Naval Research Laboratory

Stennis Space Center, MS 39529-5004

NRL/FR/7440--09-10,146

The Deterministic Mine Burial Prediction System

Paul A. Elmore
Sean E. Bradford
Kevin M. Duvieilh

Mapping, Charting, and Geodesy Branch
Marine Geosciences Division

Michael D. Richardson

Seafloor Sciences Branch
Marine Geosciences Division

January 12, 2009

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 12-01-2009	**2. REPORT TYPE** Formal Report	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE The Deterministic Mine Burial Prediction System		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER 0602782N
6. AUTHOR(S) Paul A. Elmore, Michael D. Richardson, Sean Bradford, and Kevin M. Duvieilh		**5d. PROJECT NUMBER**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER 74-6639-06
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory, Marine Geosciences Division, Stennis Space Center, MS 39529-5004		**8. PERFORMING ORGANIZATION REPORT NUMBER** NRL/FR/7440--09-10,146
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)		**10. SPONSOR / MONITOR'S ACRONYM(S)**
		11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report documents the NRL Deterministic Mine Burial Prediction System; the software, which runs in MATLAB, is an attachment to this report. The purpose of the system is to provide a user-friendly software for operating newer, deterministic, mine burial prediction models for impact and scour burial that are products of a combined six-year program between ONR and NRL. This report presents an overview of the software, documents input data and computer platform requirements, and provides a user's guide with walkthroughs of example cases. A presentation of results and analysis from exercising the system to simulate impact and scour burial experiments using operational or operational-like inputs follow. Based on nonparametric hypothesis testing of simulation results with empirical data, the statistics generated from simulations of impact burial appear to provide useful predictions and uncertainty estimates when the simulations account for geotechnical variations. For scour burial, the use of the Simulating Waves Nearshore or WaveWatch-III model to drive the scour module qualitatively followed empirical burial trends, with variations in wave height prediction appearing to be a more significant factor in determining the accuracy of the scour burial prediction than uncertainty in grain size. Overall, the tests provide encouragement for the use of new mine burial prediction models to provide reasonable predictions of burial from operational input data.

15. SUBJECT TERMS

Mine burial prediction, scour burial, impact burial, mine-countermeasures

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Paul Elmore
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	Unlimited	45	**19b. TELEPHONE NUMBER** *(include area code)* (228) 688-4613

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

CONTENTS

THE DETERMINISTIC MINE BURIAL PREDICTION SYSTEM

1. INTRODUCTION

The major objective of the Office of Naval Research (ONR) and the Naval Research Laboratory (NRL) mine burial programs during FY2001 to FY2006 was to produce an integrated time-dependent, stochastic mine burial prediction model for the operational Navy. That model should incorporate new or improved aquatic mine burial process models into a comprehensive product for predicting regional mine burial either from database input and regional oceanography models or from real-time observations. Capabilities to predict mine burial existing before these programs began were arguably poor [1]. The Deterministic Mine Burial Prediction (DMBP) system [2] presented in this report meets this goal. It consist of software that incorporates the newer models for impact and scour burial that came from the ONR/NRL experimental efforts, wrapped with a graphical user interface (GUI) to make the software more end-user friendly.

This technical report documents the system, included on the accompanying DVD. Section 2 provides an overview of the software. Section 3 presents results from exercising the system to simulate a) impact burial experiments in protected waters near Cocodrie, Louisiana; Corpus Christi, Texas; and in the Baltic Sea and b) scour burial offshore of Martha's Vineyard south of the Massachusetts Island. From these exercises, we provide guidance for software implementation. The appendixes provide end-user instructions and examples: Appendix A documents hardware requirements, installation procedures, directory contents, and software start-up; Appendix B provides a users' guide; Appendix C contains walkthrough instructions for simulating test case scenarios packaged with the software; and Appendix D lists input data requirements.

2. SOFTWARE DESCRIPTION

DMBP first calculates impact burial based on mine characteristics, bathymetry, and sediment data. Then, DMBP uses a time stepping methodology to calculate subsequent burial from scour, sand ridge migration, and liquefaction. The system may store output to a file or display predictions in a mapping product, which shows percent burial for the period covered by the oceanographic time series data. An estimate of uncertainty in the impact burial prediction is determined from statistics obtained from multiple simulations of impact burial, with random variability added to the release kinematics and/or physical properties of the mine. The software code is MATLAB™ [3] and controlled by a GUI. Models for the various burial processes are contained in separate modules and treated as black boxes, which allows for upgrades as new burial models are developed or as present burial models are improved. The sections below describe the impact and subsequent mine burial modules portions in more detail.

2.1 Impact Module

Figure 1 illustrates data flow for the impact module. DMBP uses IMPACT35 [4] to calculate impact burial. This model calculates the motion of the mine as it falls through the air, crosses the air/water

Manuscript approved December 13, 2006.

interface, continues through the water column, and penetrates into the sediment. Input data for the mine's trajectory include the following geometric, inertial and initial kinematic properties of the mine: mass, length, diameter, tapering lengths and diameters of the end, displacement of the center mass from the center of geometry, release altitude above or below the water-line, initial linear and angular velocities, and fall angle relative to the mine's axis of symmetry. Other input data needed includes water depth, density, and temperature. IMPACT35 assumes that wave action and currents have a negligible effect on mine trajectory.

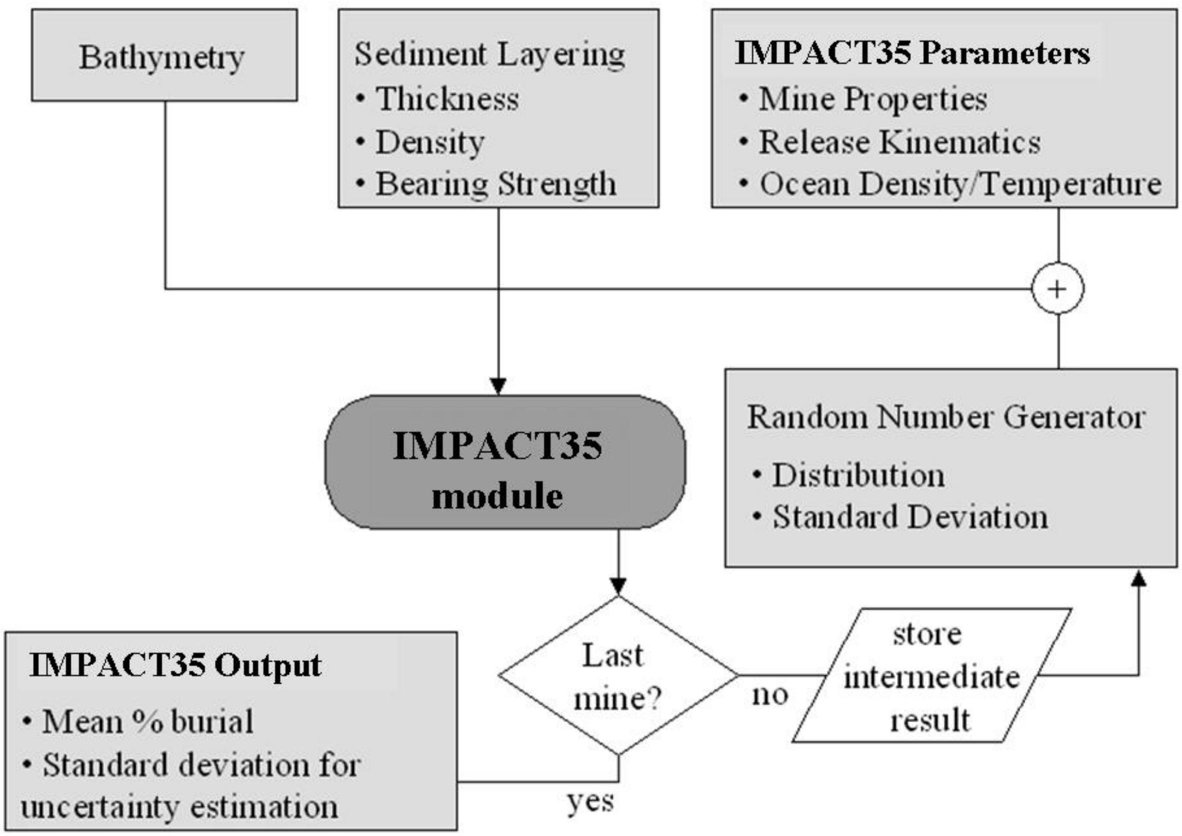


Fig. 1 – Data flow for the impact module of the DMPB

The geotechnical data needed to calculate sediment penetration are sediment bulk density and bearing strength (compression load before mechanical failure, assumed to be ten times the shear strength), expressed as a function of layer depth. One may also specify random variability of the initial conditions for the inertial and kinematic properties of the mine and, if desired, water temperature and density. Upon completing data ingest and setting initial conditions, the user specifies the number of mines deployed over the area of interest and the number of trials per deployment before executing the module. Output from this model gives the final geometry of the mine at the bottom, including resting angle, height, surface area, and volume protruding above the sediment interface. The software stores location and burial results to a file and passes this information to the scour module (see Section 2.2).

For sandy bottoms, the user may shorten execution of the impact module by recognizing that impact burial is insignificant for this type of sediment [5]. The software then assigns a user-provided value for all initial burial (parallel to the bottom) instead of computing the end burial state from the burial module.

2.2 Subsequent Burial Modules

Figure 2 illustrates data flow for the subsequent burial module. Subsequent burial processes implemented in DMBP are scour, based on Trembanis et al. [6] implementation of the HR Wallingford scour model [7-9]; liquefaction, based on the work of Sakai et al. [10]; and sand-ridge migration from Mulhearn's model [11]. The module calculates the effect of each process at each time step of the input data, during which the oceanographic conditions are to be assumed constant. DMBP stores intermediate burial results to obtain time dependent predictions of burial. In addition to location and initial burial of the mines, the module receives sediment type and bathymetry data from the impact burial part. These data, along with wave action (significant wave height and peak period) and currents (if important), are needed for post-impact burial calculations.

In this report, we only exercise the scour portion as the sand-ridge migration and liquefaction parts need verification.

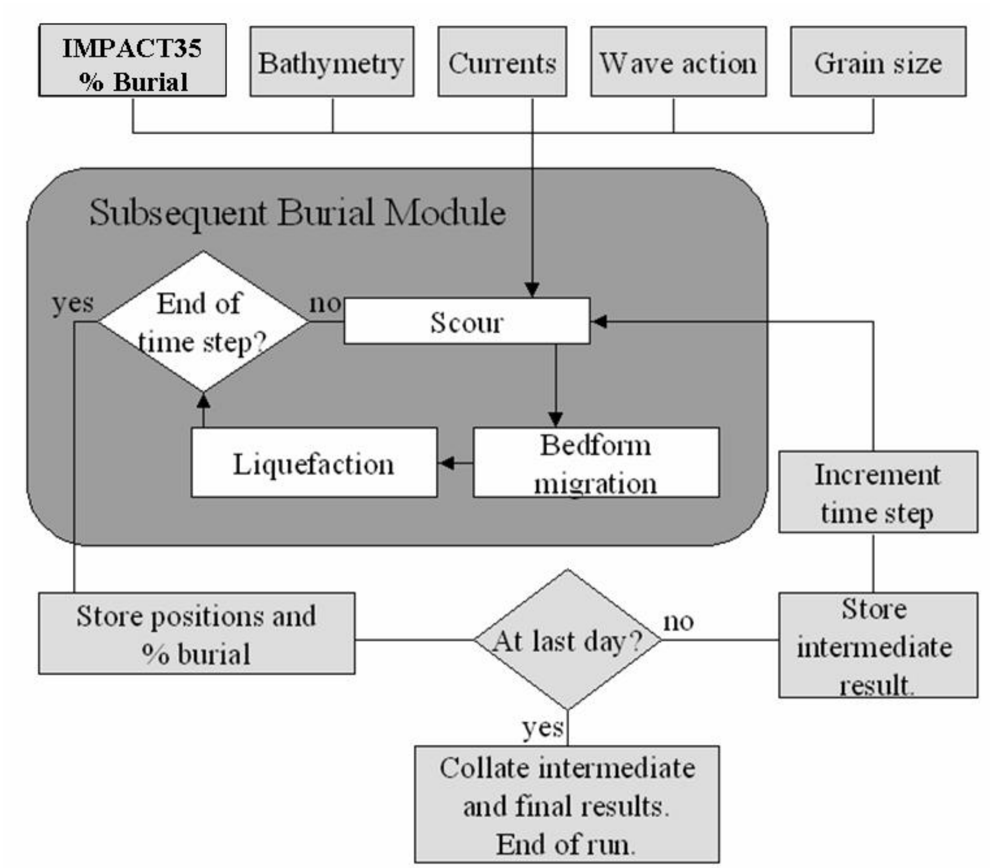


Fig. 2 – Data flow for the subsequent burial module of DMBP

3. MODEL EXERCISES

The purpose of these exercises is to examine how well the models work in their present form with operational assets to provide guidelines for software implementation. Operational resources that can be used include the Bottom Sediments Type 2.0 [12] database for sediment data, the Digital Bathymetry Data Base Variable Resolution (DBDB-V) [12] for bathymetry, and WaveWatch-III [13] and Simulating Waves Nearshore (SWAN) [14] models for oceanographic forecasts.

It is important to keep in mind that for operational data sources, the environmental detail is often less than that obtained during experiments. For example, sediment data sets are often polygon provinces of sediment type based on interpolation of sparsely distributed data. Database creators often assign values of median grain size, bulk density, porosity and acoustic impedance based on the sediment description (i.e., fine sand or silty-clay). Information that is more detailed is too spatially or temporally variable to obtain and maintain on a worldwide basis pragmatically.

3.1 Impact Burial Exercises

3.1.1 Experimental Data

Trials for the impact burial portion of DMBP involved comparing predicted burial against measured burial obtained during three experiments: 1) in protected waters near Cocodrie, Louisiana, conducted in January 2002; 2) in the Gulf of Mexico, offshore from Corpus Christi, Texas, conducted in May 2002; and 3) in offshore waters of the Baltic Sea, conducted in June 2003. Table 1 lists the physical properties of the two types of mines used in these experiments.

	FWG mine	"Thumper" mine
Mine Length	1.7 m	2.400 m
Mine Diameter	0.47 m	0.533 m
Tapered Diameter	0.395 m	0.533 m
Taper Length	0.150 m	0.000 m
Mine Area	4.134 m2	4.465 m2
Mine Volume	0.287 m3	0.516 m3
Mine Mass in Air	500 kg	1017 kg
Center of Mass Offset	0.000 m*	0.104 m

*Assumed due to tethering

Table 1 – Baseline inertial properties of the NRL "Thumper" and FWG optical mines. The center FWG mass offset for the FWG mine is set at 0.0 m, as the mine remained tethered during the entire deployment.

For all drops, the initial vertical velocity, horizontal velocity, and rotation rate perpendicular to the axis of symmetry were zero (i.e., the mines were deployed from a ship at anchor).

.

For the Cocodrie and Corpus Christi experiments, discussed in Abelev et al. [15], only the NRL Impact Burial Mine was used.

Table 2 lists release positions of the mine used during these experiments. The waters were 16 m deep for both locations. The mine fell freely through the water column after release from the ship's winch; divers assisted in recovery and recorded observed burial. The mine contained internal fiber optic gyro, accelerometers, and electronics to record acceleration and rotation. A reversed integration technique [16] calculated the volume buried after impact; these assessments of burial agreed with diver observations.

Cocodrie				Corpus Christi			
Drop Number	Core Number	Altitude (m)	Pitch (degrees)	Drop Number	Core Number	Altitude (m)	Pitch (degrees)
1	1	-0.5	0	12	5	-0.5	0
2	1	-0.5	0	13	6	-0.6	0
3	1	-0.5	31	14	6	-1.5	31
4	2	1	31	15	6	0.5	0
5	2	0.5	31	16	7	-0.8	0
6	2	1	0	17	7	-0.8	0
7	3	0.2	0	18	8	-0.6	0
8	3	-0.5	0	19	8	-0.8	0
9	3	-0.5	31	20	9	-0.6	0
10	3	-0.5	31	21	9	-0.6	0
11	4	0.2	31				

Table 2 – Variations in the initial release conditions for the Cocodrie and Corpus Christi experiments. A negative altitude means an underwater release.

The Baltic Sea experiment, discussed in Weaver et al. [17], involved 59 drops using the German FWG optical mine [18] in a region between 23.5 and 26.5 m deep. All release positions were horizontal and 1 m above the surface. The mine had three rings (one near each end and the other in the middle) of optical transmitter-receiver sets that were spaced at 15-degree intervals around the circumference of the hull. The number of optical sensors blocked by the sediment after impact provides an estimate of the surface area of the mine buried. All releases were 1 m above the sea surface with both initial velocity and rotation zero. The FWG mine remained tethered to the ship's winch for mine recovery without divers. The tether allowed only a zero pitch angle (i.e., axis of symmetry parallel to the water surface). The effect that tethering had on velocity and rotation is not known; however, it is assumed that the tether only prevented mine rotation as both ends were attached to the tether. Thus, for modeling purposes, the setting for the center of mass offset was zero (the cylinder does not rotate in IMPACT35 for this condition).

In both experiments, the scientific parties collected sediments as close to the mine drop positions as possible using gravity corers. Analysis of the cores provided sediment bulk density at 1-cm intervals using gamma ray attenuation and shear strength profiles from linear interpolations of vane instrument measurements at representative (two to four) locations. To approximate bearing strength, the shear strengths were multiplied by ten [19]. Table 3 lists the median, mean, and standard deviation of these data for each experiment site. Figure 3 displays the bearing strengths and density data for all three experiments.

The Baltic Sea data (Fig. 1 (c-d)) show two different sediment types for the experiment area. In the discussions that follow, the hard sediment data correspond to cores 1-16 (assumed to be from a common area) and the soft sediment data to cores 17-58. Thus, for the Baltic Sea data, Table 3 gives the statistics for all data combined, followed by the hard sediment and soft sediment subsets.

	Cocodrie		Corpus Christi		Baltic Sea	
	K (kPa)	ρ (kg/m^3)	K (kPa)	ρ (kg/m^3)	K (kPa)	ρ (kg/m^3)
Median	82	1700	34	1690	50, 170, 140	1360, 2090, 1310
Mean	80	1710	32	1705	110, 270, 43	1520, 1960, 1340
Standard Deviation	44	70	20	80	180, 270, 35	330, 290, 100

Table 3 – Median, mean, and standard deviations for the bearing strengths (K) and densities ρ measurements from the Cocodrie, Corpus Christi, and Baltic Sea experiments (the Baltic Sea numbers correspond to using all sediment data, the hard sediment data only, and the soft sediment data only, respectively). For the Cocodrie and Corpus Christi data, these numbers correspond to the top 0.4 m of sediment.

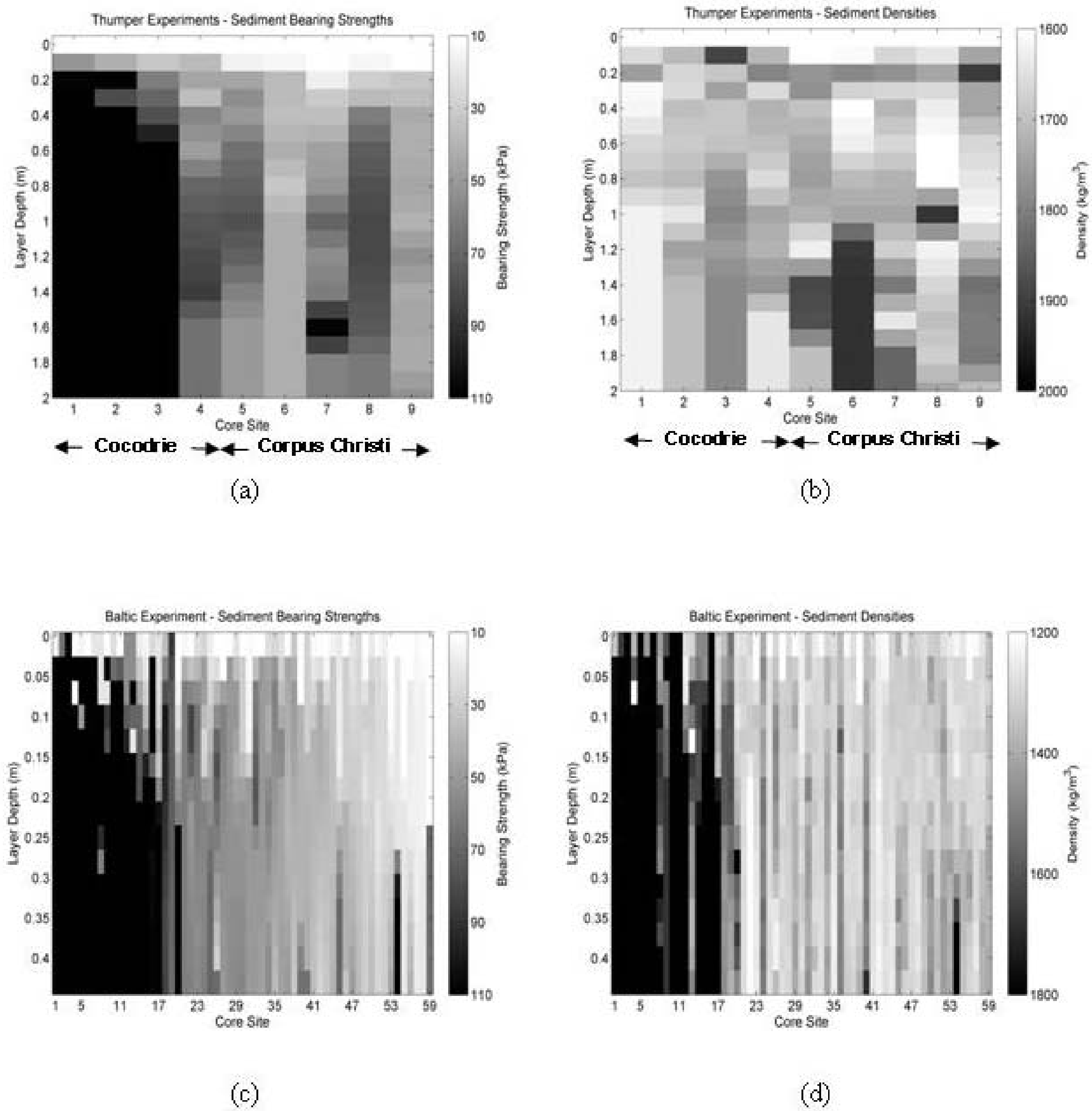


Fig. 3 – (a) Bearing strength and (b) density data (both provided by A. Abelev) for the Cocodrie (cores 1-4) and Corpus Christi (cores 5-9) experiments where the NRL Impact Mine was deployed. Site number is in temporal order of sites visited during the two cruises. Subfigures (c) and (d) show bearing strength and density, respectively, for the Baltic Sea sites where the FWG optical mine was deployed. Data arranged in order of decreasing median bearing strength.

3.1.2 Case-by-Case Predictions

The impact module was run for each case using the values of sediment bulk density and bearing strength, water depth, and initial mine release conditions corresponding to each drop. Water density and temperature were set to 1030 kg/m^3 and 10 ºC, respectively. Since the impact module only accounts for cylindrical or tapered cylinder mines, the model runs assumed that the Thumper mine had two blunt ends (it has a blunt end and a hemispherical end) and that the FWG mine had two tapered ends (it has one chamfered and one tapered end).

Figure 4 plots the differences between empirical data and model predictions. For the Cocodrie and Corpus Christi simulations, there appears to be no tendency to either over- or underpredict burial. The Baltic Sea calculations appear to underpredict burial, except for the sediments that had the lowest median bearing strengths where burial is overpredicted; a hypothesized cause of this disagreement is that the sediment did not refill the impact crater to cover the upper sensors, thereby limiting the maximum measurement of burial to approximately 50%. (Burial measurements appear peak at 50% in the softest sediments; however, model predictions and extrapolation of the empirical data suggest that burial should have continued to increase beyond 50% with decreasing bearing strength.) Both results show that the model does not provide reliable case-by-case predictions of burial, especially since there are outliers in the data that are in disagreement by 40% to 50%.

(a)

(b)

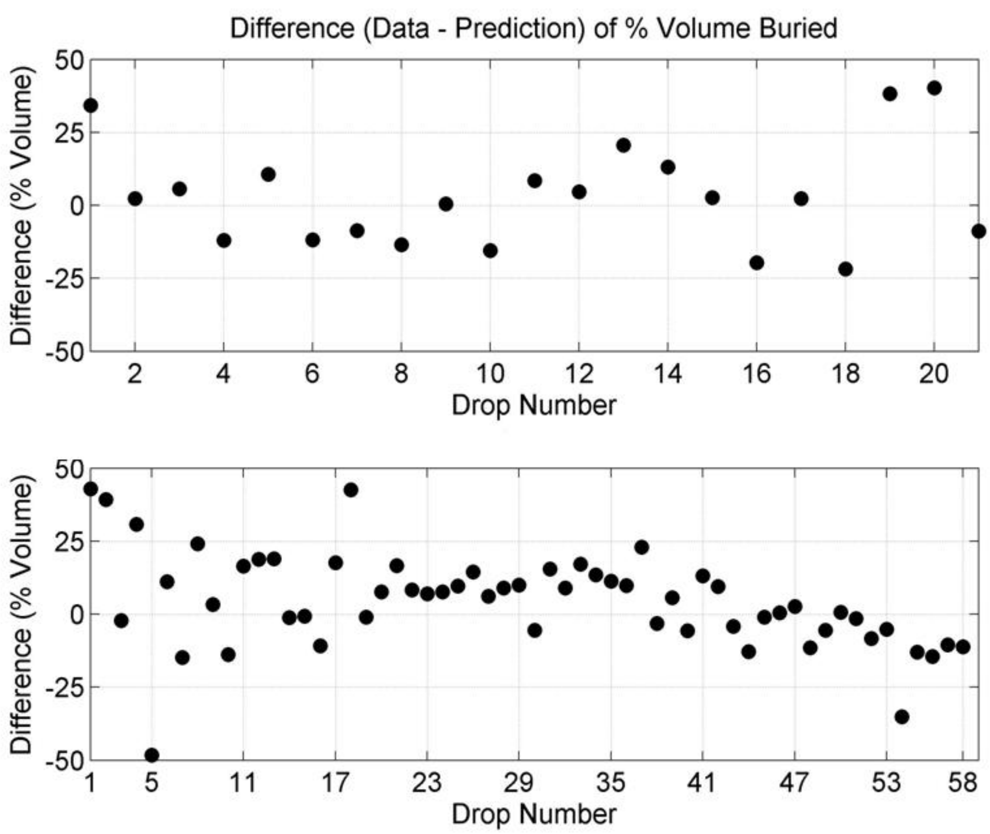


Fig. 4 – (a) Difference between burial data (provided by A. Abelev) and predictions for the Cocodrie and Corpus Christie experiments; a positive number indicates underprediction. The "Drop Number" axis corresponds to the release conditions in Table 2. (b) Burial data and predictions for the Baltic Sea experiment. Here, the "Drop Number" axis corresponds to the core data in Figs. 1(c-d).

The statistics of the predictions, however, appear to provide observable trends. The first two rows of Table 4 give the median, mean and standard deviation of the experimental data and case-by-case predictions, respectively. The fonts indicate the results of nonparametric hypothesis testing using MATLAB™ implementations of two-sided Kolmogorov-Smirnov and Wilcoxon rank sum tests [20] to check for statistically significant differences between empirical data and predictions (use of nonparametric tests allows for hypothesis testing without any assumptions on the distribution of the data). The tests indicate no significant differences between the measured and predicted burial for the Cocodrie, Corpus Christi, and the hard sediment Baltic Sea cases at a 95% confidence level. There are significant differences between predictions and data when the soft Baltic Sea sediment sites are taken into account, even though the statistical means of the simulations fall within one standard deviation of the measurements. When these data sets do not include points corresponding to overprediction (i.e., consider only sites 1-41 and throw out sites 42-58), however, the hypotheses tests indicate no significant differences between the data and simulation results.

	Cocodrie	Corpus Christi	Baltic Sea (all)	Baltic (hard)	Baltic (soft)
Experiment	32, 30, 14	49, 54, 24	52, 49, 14**	40, 36, 18	54, 54, 6
Case-by-Case	**31, 29, 5**	**46, 46, 8**	*(55, 53,17)***	**32, 32 ,11**	*(62, 62, 10)*
MC Sim 1	**31, 30, 4**	*(34, 36, 8)*	*(29, 30, 4)*	*(13, 13, 1)*	*(35, 35, 4)*
MC Sim 2	**32, 31, 4**	*(30, 35, 8)*	*(30, 31, 5)*	*(13, 14, 2)*	*(35, 36, 6)*
MC Sim 3	**28, 28, 4**	*(30, 35, 8)*	*(27, 28, 4)*	*(13, 13, 1)*	*(31, 32, 4)*
MC Sim 4	*(39, 39, 9)*	**43, 55, 12**	*(43, 43, 17)*	*(23, 23, 9)*	*(49, 50, 12)*
MC Sim 5	**33, 34, 7**	**45, 48, 9**	*(40, 38, 14)*	*(21, 21, 7)*	*(45, 45, 9)*

Table 4 – Statistical analysis of empirical impact burial data (% volume buried) and simulation results. The numbers in each cell are median, mean, and standard deviation in that order. The columns correspond to Cocodrie, Corpus Christie and Baltic Sea sites, with the Baltic Sea divided into cases using all core data (total), only cores 1-16 (hard) and only 17-58 (soft). The rows correspond to empirical data, case-by-case predictions, and results from the five Monte Carlo simulations (MC Sim), where MC Sims 1-3 use a half-space bottom and MC Sims 4 and 5 use the core data. Bold font indicates no statistical difference (i.e., non-rejection of the null hypothesis) at the 5% significance level between experimental data and simulation results using two-sided Kolmogorov-Smirnov and Wilcoxon rank sum tests. Numbers in italics and parentheses indicate rejection of the null hypothesis for either tests. Empirical data is in normal font. **When tests of the Baltic data sets consider only sites 1-41, the tests indicate no significant difference between the empirical data [52, 48, 15] and case-by-case simulations [50, 46, 14]; the null hypothesis is still rejected for the corresponding Monte Carlo results.

Hence, even when one has knowledge of the release conditions and geotechnical properties of the sediment to the level presented here, it is difficult to achieve agreement between individual predictions and empirical data points for impact burial. One should use a statistical approach instead. Abelev and Valent [21, 22] reached this conclusion, suggesting that Monte Carlo simulations with a deterministic impact burial model may provide predictions whose statistics may match more closely with experimental results. Section 3.1.3 explores this possibility further.

3.1.3 Monte Carlo Predictions

In this section, we examine how close Monte Carlo simulations of impact burial match experiment using two different bottom models – an infinite half-space and a layered bottom using core data from the experiments. The objective is to see if simulation can match experimental results when a half-space model of the bottom is used or if more detailed knowledge of the sediment may be required. When performing these simulations, some kinematic properties of the mine are randomized as these conditions often are unknown and may not be equal among individual drops. Table 5 lists the release conditions used. The inertial conditions are set to the values specified in Table 1. (There can be variations of inertial properties, but in these simulations, we assume that manufacturer variations are insignificant.)

	MC Sim 1	MC Sim 2 & 4	MC Sim 3 & 5
Altitude	0 m	1 m	1 m
Fall Angle	180 $\pm$ 180 degrees	180 $\pm$ 180 degrees	180 $\pm$ 180 degrees
Rotation Rate	0 deg/s	0 deg/s	180 $\pm$ 180 deg/s

Table 5 – Variable kinematic properties for Monte Carlo simulations (MC Sim) of the impact experiments. MC Sims 1 through 3 use a half-space bottom and MC Sims 4 and 5 use the core data. Random quantities are uniformly distributed.

We performed five Monte Carlo simulations. Simulations 1, 2, and 3 use a half-space bottom. The bearing strength and density were derived from the overall median values (to lessen the effects of outlier points) of these parameters from each experiment. Simulations 4 and 5 use the same kinematic randomization of 2 and 3, respectively, but use the core data rather than the half-space approximation.

Table 4 gives the results of the Monte Carlo simulations. Each half-space simulation had 100 events and produced a median, mean, and standard deviation of the percent volume buried; simulations 4 and 5 computed burial from 100 drops over each core site. (The means and standard deviations of the Monte Carlo simulations appeared to converge to stable values well before reaching the maximum sample size.) The study used Kolmogorov-Smirnov and Wilcoxon tests again to check for statistically significant differences between simulations and empirical data. As before, the font indicates non-rejection or rejection of the null hypothesis.

From these data, we make the following observations: 1) Accepted matches (i.e., no significant differences) between experiment and Monte Carlo results occur when the simulations use the sediment parameters from the core data, 2) statistically significant differences appear when the simulations use the half-space bottom for two (Corpus Christi and Baltic Sea) of the three experiments, and, unexpectedly, 3) there is a dependence on rotation rate for the Baltic Sea cases – adding in rotation when was not any made the simulations and data disagree significantly.

Thus, from these observations, it appears that the end-user should use a layered geotechnical model for the bottom and a reasonable rotational rate of the mines when using the impact module.

3.2 Scour Burial Exercises

3.2.1 Experimental and Computational Data

Tests for the scour burial portion of DMBP involved hindcasts for an ONR/NRL experiment carried out at the Martha's Vineyard Coastal Observatory (MVCO) [23], located off the southeastern coast of the island, from October 1 to 5 December 5, 2003. Experimental time-series data for scour burial depth were the pressure sensor records (with corrections made for tides) on the NRL Acoustic Instrumented Mines (AIMS) [24] deployed in fine sand (median grain size 0.15 mm) for the experiment. Trembanis et al. [6] present calculations of burial using corrected hindcasts from WaveWatch-III [25], a deep-water model designed to provide predictions that are global or oceanic in extent. For this study, the scour module utilized significant wave height and period output from SWAN Version 40.41 [26] for time-series input. The motivation for using SWAN is that it is a shallow-water wave model and, for operational scenarios, it may be the source of high-resolution wave forecasts in littoral regions.

3.2.2 SWAN Input Data

The source for bathymetric input data (at 6 arc-second resolution) for SWAN was the National Geophysical Data Center (NGDC) archives [27], shown in Fig. 5. The WaveWatch-III archive [27] at the National Centers for Environmental Prediction (NCEP) was the source for the wind forcing [28, 29] and parametric wave (significant wave height, peak wave period, and peak wave direction at three-hour increments at 0.25 degrees increments) input data. This archive, however, lacks information on directional spreading that is also required by the SWAN, so the model used the default value (for stationary runs) of 30 degrees for all time steps.

3.2.3 Benchmarking

This study tested the present implementation of SWAN against a benchmark case. The benchmark is a hindcast for the Martha's Vineyard area (40.4N to 41.8N by 71W to 69W at 0.05 degree of grid resolution) from February 1, 2004, 1200Z to February 9, 2004, 0600Z created from the SWAN Version 40.11 module of the Distributed Integrated Ocean Prediction System (DIOPS) suite [30]. This run used spectral wave data (frequency and directional space metrics quantify wave energy rather than just peak information) obtained from WaveWatch-III and wind forcing from the Western Atlantic grid of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™) [31] for input; both were from Fleet Numerical and Oceanographic Command (FNMOC). The SWAN Version 40.11 iteration time step was 15 minutes and boundaries over water coincided with at least five points of WaveWatch-III output.

The runs of SWAN Version 40.41 used the input data described in Section 2.2 with 10-minute iteration steps and the same computational grid as the benchmark case. All SWAN options [32] were set at the default settings, except for the numerical accuracy parameters and bottom friction (friction is off by default). For an iteration to terminate, the significant wave heights and periods had to vary less than 10% and 15%, respectively, for 67% of the grid points over water within 20 iterations. Any improvements using shorter iteration steps or more stringent accuracy requirements were not apparent. The runs also used the "JONSWAP" option to account for bottom friction (this is the default friction option after activating friction in the model and is based on a semi-empirical model derived from the Joint North Sea Wave Project (JONSWAP) results [33]) with the default coefficient of 0.067.

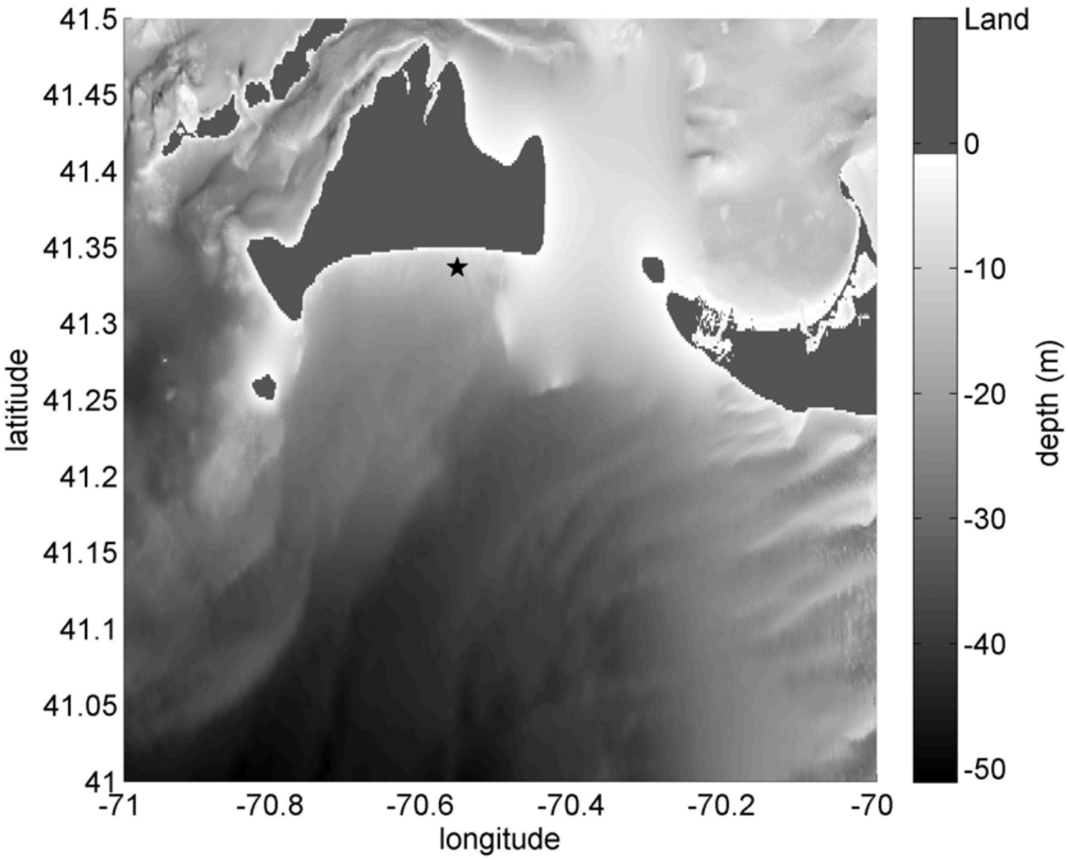


Fig. 5 – Bathymetry data for the Martha's Vineyard region at 6 arc-seconds of resolution. The black star below the south side of the island plots the position of the experiment site. SWAN runs actually used a larger window of bathymetry data; this display matches the field of view for Fig. 10.

Figure 6 shows a comparison of the predicted significant wave heights from WaveWatch-III and the two SWAN runs for the grid points closest to the MVCO node. The figure also plots significant wave height from the RMS time-series of an acoustic Doppler velocity profiler at the instrumented node at the observatory. The outputs from all three models qualitatively appear to follow the empirical data, although the errors for SWAN are higher than the average RMS error of approximately 0.3 m given in SWAN verification studies [34, 35]. These errors are 0.63 m for WaveWatch-III, 0.42 m for SWAN, and 0.57 m for the DIOPS run. These higher errors may be due to the instrument node being located closer to shore than the nearest computational grid points that are located over water. The node was located at 41.3367N, 70.5565W at a depth of 12 m. For the SWAN data, the closest grid point is located at 41.30N, 70.55W, 2.24 nmi seaward from the node, at a depth of 22 m. The nearest WaveWatch-III data grid point is at 41.25N and 70.50W, 11.5 km seaward from the node, at a depth of 31 m. Although this error may have been reducible by shifting the grid so that a grid point fell at the experiment site, this type of error may be typical of operational forecasts for mine countermeasure operations because the position of a mine or group of mines may be unknown.

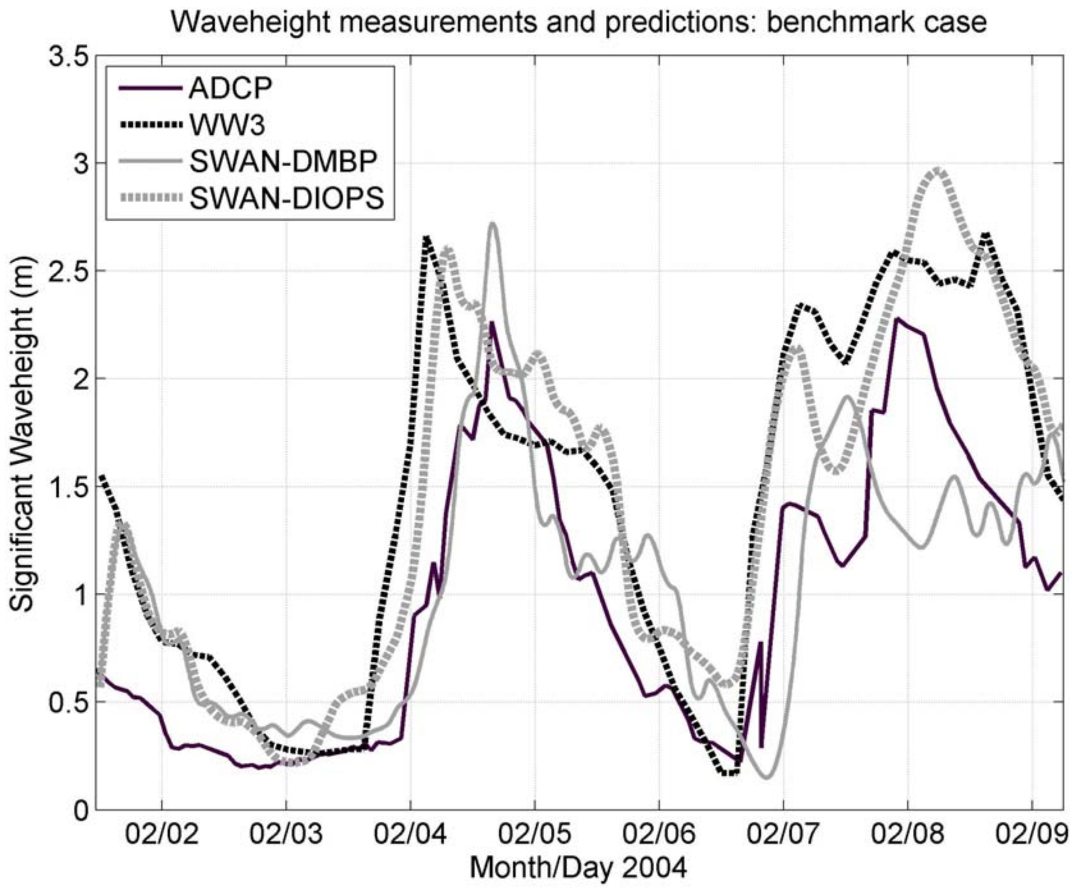


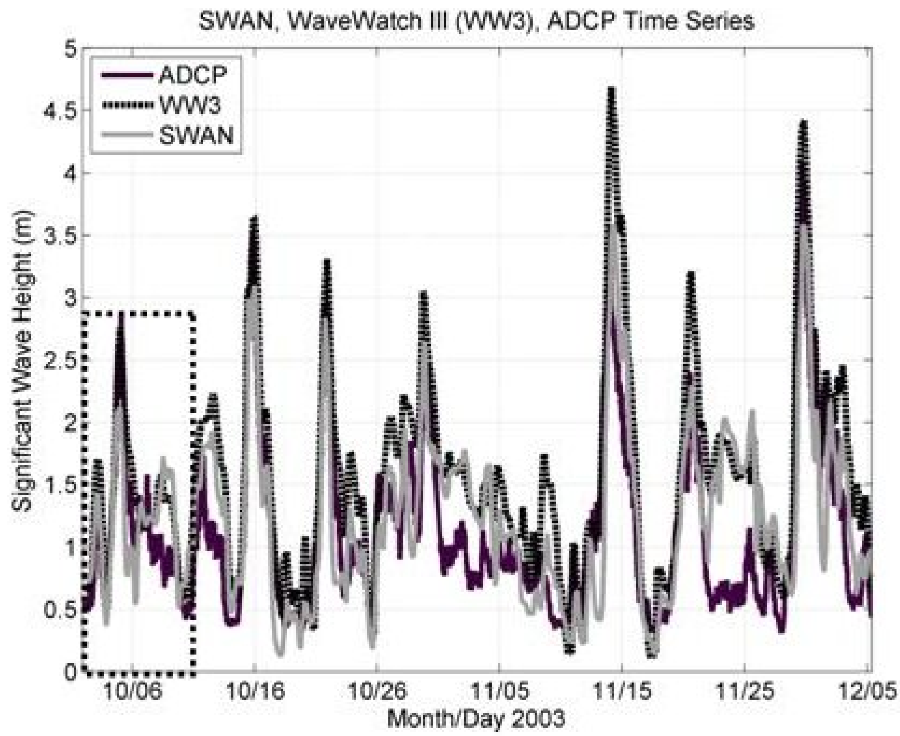
Fig. 6 – Wave height measurements and predictions for the Martha's Vineyard benchmark case. Measurements are from the Martha's Vineyard Coastal Observatory instrument node. Predictions from WaveWatch-III (WW3) and SWAN are for the nearest oceanic grid point to the node. The "SWAN-DMBP" line is output for SWAN version 40.41 using the peak oceanography data and NCEP winds for input. The "SWAN-DIOPS" line is output for SWAN version 40.11 using spectral oceanographic data and COAMPS™ winds for input.

3.2.4 Comparison of Scour Hindcast Results with Experiments

SWAN computed a hindcast of significant wave heights, peak period and peak direction for the ONR/NRL Martha's Vineyard mine burial experiment held from September 30, 2003, to December 5, 2003, using input files described in Section 3.2. The hindcast starts at 2100Z on the first day and ends at 0900Z on the last. The Sediments 2.0 database reports that the entire region is sand with a median grain diameter of 0.35 mm; the measured grain size is 0.15 mm for fine sand sites and 0.75 mm for coarse sand sites. Thus, the assumed initial burial is 10% to account for settling.

Figure 7(a) shows time series data for the significant wave height at the experiment site for the entire experiment. Figure 7(b) displays a close-up of the data for the first ten days. The RMS errors were 0.59 m for WaveWatch-III and 0.48 m for SWAN. Periods of consistent overprediction appeared to occur when the waves were coming from the open Atlantic Ocean, heading in a north to north-northeast direction. Since the SWAN and WaveWatch-III grid points are in deeper water than the MVCO node, bottom friction may have reduced wave energy by the time these waves reached the node. Overprediction does not always occur, however, as seen by the storm event on October 5. SWAN predicted the significant wave height to be approximately 2.0 m while the empirical data shows that the height was 2.9 m.

(a)



(b)

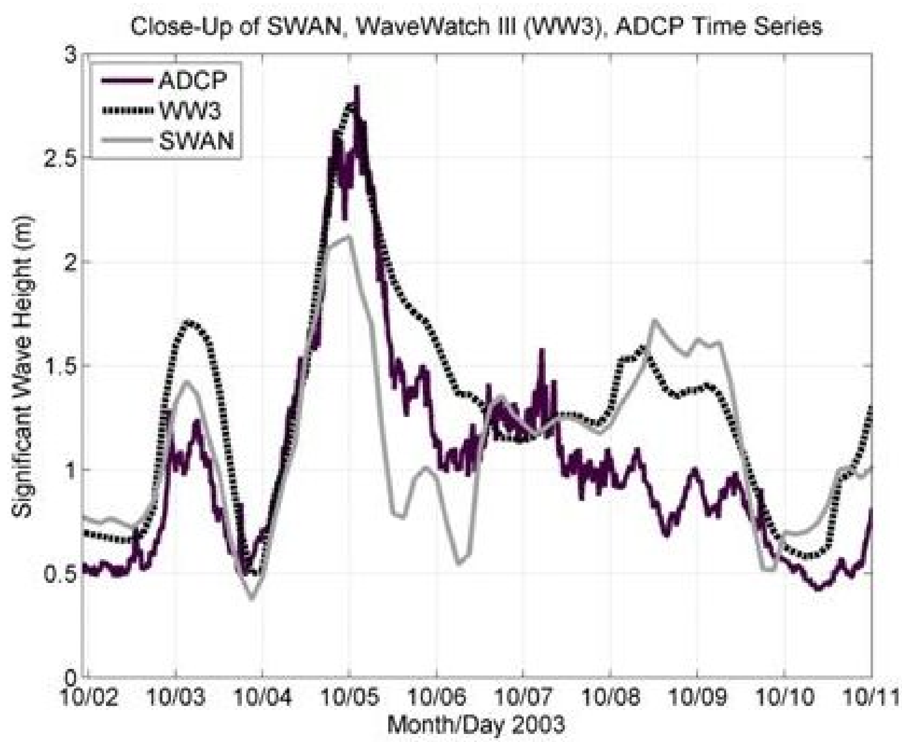


Fig. 7 – Time series hindcasts for significant wave heights during the Martha's Vineyard mine burial experiment for (a) the entire experiment and (b) the first ten days. The figures plot the data as obtained from acoustic Doppler current profiler (ADCP) measurement statistics and as predicted by WaveWatch-III (WW3) and SWAN.

Orbital velocity computations followed the procedure in Soulsby [8]. Figure 8(a) presents the burial predictions for the fine sand site using the resultant orbital velocity data as computed from ADCP, WaveWatch-III, and SWAN time series. Figure 8(b) shows a close-up of the burial predictions for the first ten days. These figures also display empirical burial data, determined from the average time-series of the pressure sensors (corrected for tides) recorded by the AIMS mines deployed in fine sand. Model predictions qualitatively follow the empirical data, although there is some initial underprediction using the SWAN data due to the underpredicted wave heights on October 5. As expected from Ref. 6, burial correlates with increased significant wave height due to increased bottom friction and occurs rapidly during the event on October 5. The model, however, does not account for re-exposure, so these events, visible in the empirical data in Fig. 8(a), do not appear in the predictions.

An examination of the effect uncertainties in wave height prediction and grain size shows that the scour model is more sensitive to errors in wave height prediction than in median grain size. Figure 9(a) displays predictions obtained by adding uncertainties of $\pm$ 0.3 m to the SWAN wave height time series, the assumed nominal error for SWAN predictions [34, 35], while keeping the grain size constant at the database value of 0.35 mm. The range of burial is approximately $\pm$ 22% until nearly or complete burial is reached. (Errors in the wave period of $\pm$ 0.7 s as reported by [35] were also propagated through the scour model and only resulted in a $\pm$ 2% difference in scour burial depth). Figure 9(b) gives similar curves for the empirical and database grain sizes of 0.15 mm, 0.35 mm and 0.75 mm. Here, the uncertainty is typically only a few percent and approximately $\pm$ 8% at worst. For this case at least, accurate wave height predictions appear to be crucial to obtaining good scour burial predictions, more so than minimizing uncertainty in grain size.

3.2.5 Regional Hindcast

Using gridded bathymetry and sediment data, the SWAN hindcast drove the scour model over a 30 arc-sec bathymetry grid for the Martha's Vineyard region to produce regional scour burial predictions. Figure 10(a–d) shows predictions of regional mine burial during the experiment. The amount of burial qualitatively correlates with bathymetry (cf. Fig. 3). The initial burial discussed above is apparent in Fig. 10(b), with the prediction of 100% burial for the experiment site. Scour at higher amounts and greater depths appear after the larger storm events of November 15 and 30.

(a)

(b)

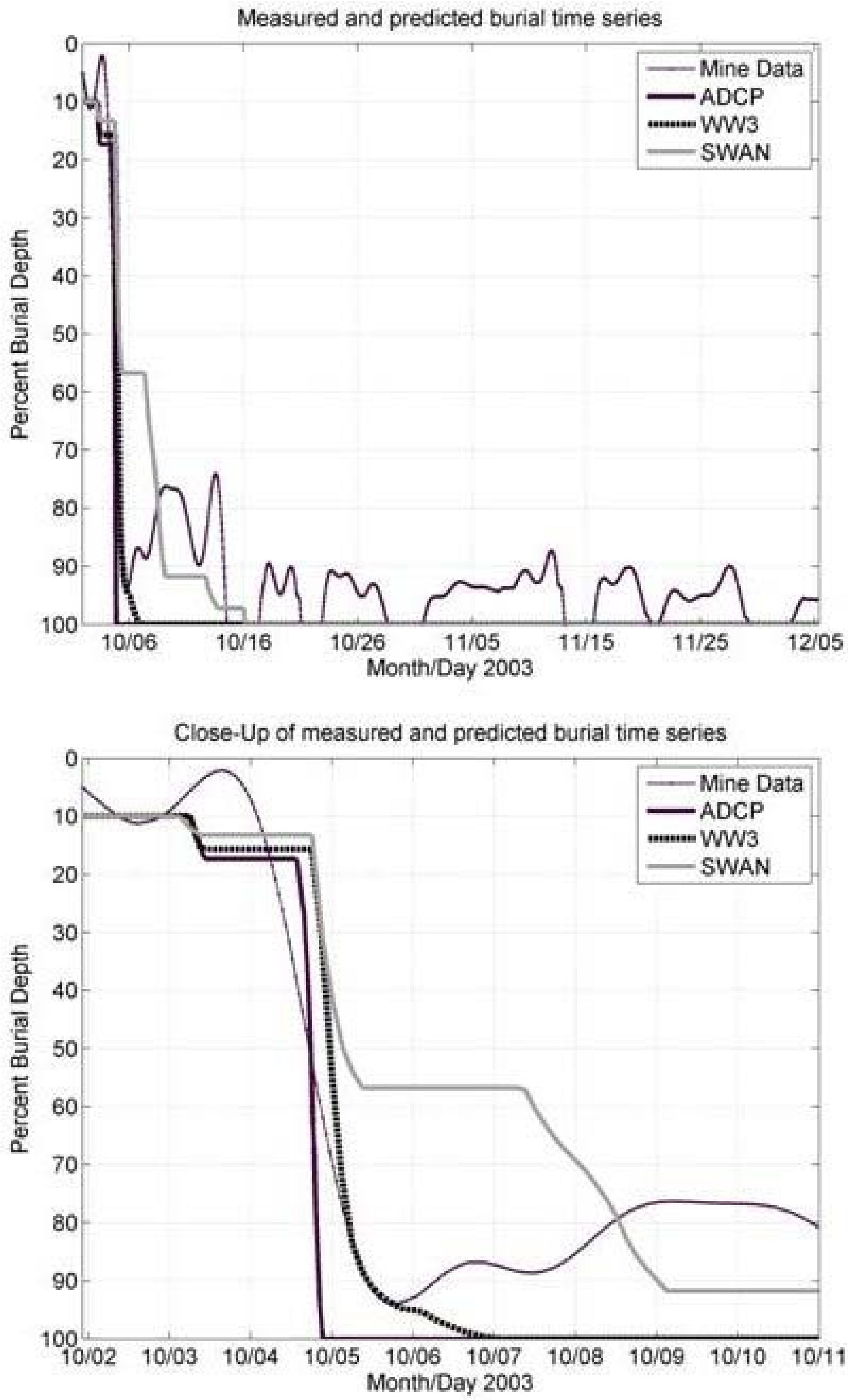
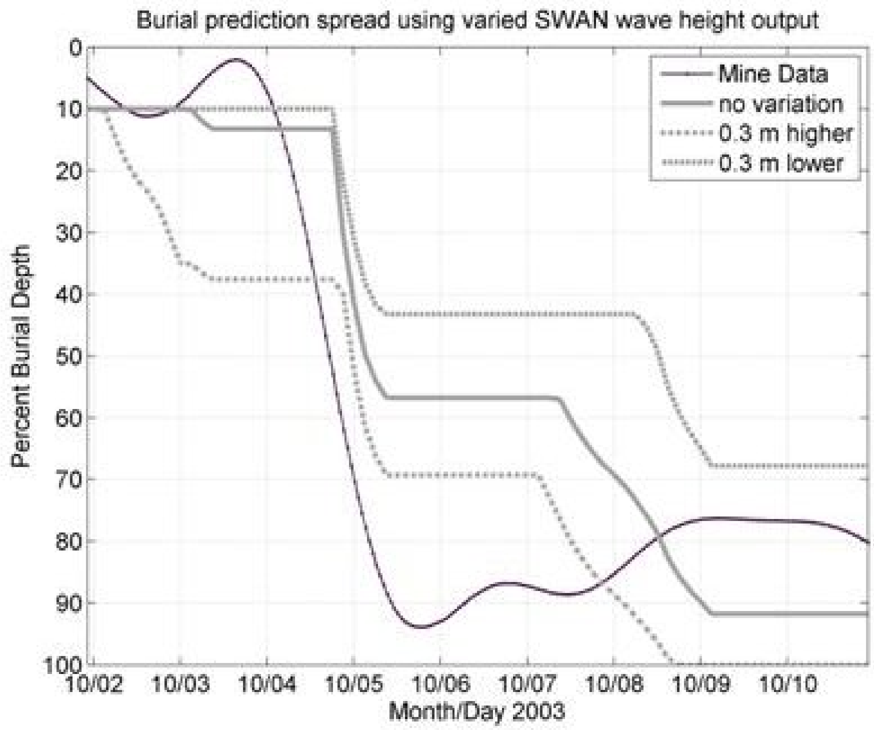


Fig. 8 – Predicted burials for the Martha's Vineyard mine burial experiment for (a) the entire experiment and (b) the first ten days. The figures plot an empirical burial curve, obtained from the averaged burial time-series from the two AIMS in fine sand (0.15 mm), and predictions obtained from driving the scour model using the time series data in Fig. 5.

(a)



(b)

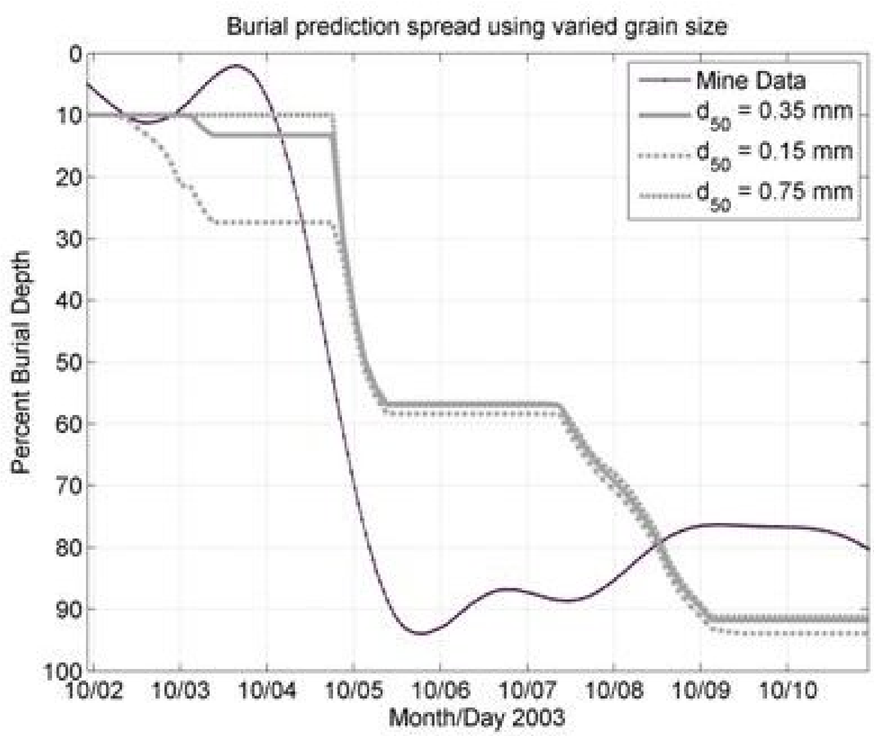


Fig. 9 – Difference in burial predictions due to (a) variations in the significant wave height of the SWAN prediction, leaving median grain size d_{50} = 0.35 mm (the value reported for this area by the Sediments 2.0 database) and (b) variations in the median grain size but using the unaltered SWAN data

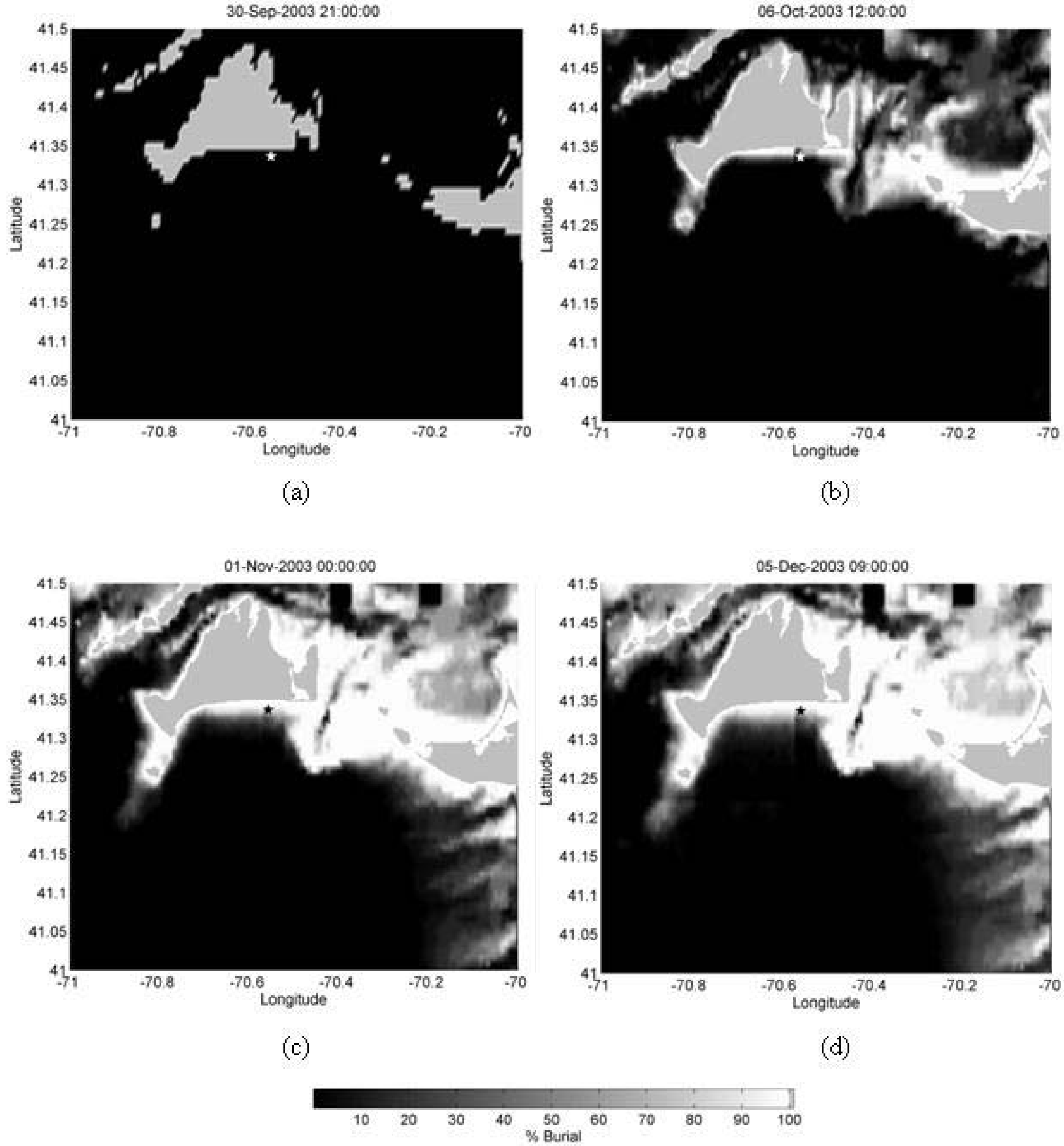


Fig. 10 – Regional burial hindcasts for the Martha's Vineyard mine burial experiment with bathymetry at 30 arc-sec of resolution and SWAN predictions at 0.05-deg resolution. The predictions are for (a) the beginning of the experiment – 2100Z, September 20, 2003, (b) 1200Z, October 6, 2003, (c) 0000Z, November 1, 2003 and (d) the end of the fourth experiment, 0900Z, December 5, 2003. The assumed initial burial and grain size are 10% everywhere and 0.35 mm, respectively. The star plots the position of the experiment site.

4. SUMMARY

This report documents the NRL Deterministic Mine Burial Prediction System; the software, which runs in MATLAB, is an attachment to this report. The purpose of the system is to provide a user-friendly software for operating newer, deterministic, mine burial prediction models for impact and scour burial that are products of a combined six-year program between ONR and NRL. This report has presented an overview of the system and results from exercising it. The appendices document input data and computer platform requirements and provide a users' guide with walkthroughs of example cases.

After exercising the system to simulate impact and scout burial, we make the following recommendations to the end user:

- For impact burial, use layered geotechnical data and rotational rates that are realistic to provide predictions that match with experiments.

- For scour predictions, the SWAN model (using archived WaveWatch-III data for input) may be used to drive the scour module, keeping in mind that
  - Uncertainty in significant wave-height causes large error in the burial forecasts.
  - Uncertainty in grain size causes less error.
  - The model does not account for re-exposure. Accurate scour burial predictions appear to require accurate significant wave height data.

This exercises also demonstrated the use of SWAN hindcasts to produce a nonstationary, two-dimensional scour burial forecast as a mapping product.

A strength of the DMBP system is that its predictions come from direct, forward computation from deterministic models. Thus, it is capable of producing forecasts for mine burial based on up-to-date ocean modeling forecasts and geotechnical information. This capability can be useful for training expert systems that rely on archived probability tables, as discussed by Rennie et al. [36].

ACKNOWLEDGMENTS

The authors wish to especially recognize and thank Peter Chu and Chenwu Fan for providing the IMPACT35 code, Carl Friedrichs and Art Trembanis for providing code for the scour module, Phil Mulhearn for the sand-ridge migration code, Andrei Abelev and Phil Valent for providing data from the Cocodrie and Corpus Christi experiments, Rick Allard for setting up and providing the input data for the Martha's Vineyard benchmark case on the DIOPS system, and Thomas Wever and Mark Frazer for providing data from the Baltic Sea experiment. The authors would also like to thank Will Avera, Alan Brandt, Tom Drake, Peter Fleischer, Nathaniel Plant, Sarah Rennie, Erick Rodgers, Peter Traykovski, Linwood Vincent and an anonymous reviewer for their helpful discussions and suggestions. The mention of commercial products or the use of company names does not in any way imply endorsement by the U.S. Navy. ONR/NRL Base funds (Program Element: 0602782N) provided funding for this project.

REFERENCES

1. M.D. Richardson and K.B. Briggs, "Seabed-Structure Interactions in Coastal Sediments," *Proceedings of the 4th International Symposium on Technology and the Mine Problem*, March 13-16, 2000.
2. P.A. Elmore and M.D. Richardson, "Regional Mine Burial Prediction Using Monte Carlo and Deterministic Methods," *Proceedings of the Sixth International Symposium on Technology and the Mine Problem*, .
3. The Mathworks, 2005. MATLAB, Version 7.0.4, The Mathworks Inc., Natick, MA.
4. P.C. Chu, C. Fan, A. Evans, A. Gilles, T.B. Smith, and V. Taber, "Development and Verification of 3D Mine Impact Burial Prediction Model," *IEEE J. Oceanic Engin*., in press, 2007.
5. *Handbook for Marine Geotechnical Engineering,* Naval Civil Engineering Laboratory, Port Hueneme, CA, 1985.
6. A.C. Trembanis, C.T. Friedrichs, M.D. Richardson, P.A. Traykovski, P.A. Howd, P.A. Elmore, and T.F. Weaver, "Predicting Mine Scour Burial at Indian Rocks Beach, Florida and Martha's Vineyard, Massachusetts," *IEEE J. Oceanic Engin.*, in press, 2007.
7. P.A. Elmore and M.D. Richardson, "Assessing Scour Model Performance with Experimental Data," *Proceedings of the IEEE/MTS Oceans 2003 Conference,* 2350-2354.
8. R. Soulsby, *Dynamics of Marine Sands: A Manual for Practical Applications* (Thomas Telford, London, 1997).
9. R.J.S. Whitehouse, *Scour at Marine Structures: A Manual for Practical Applications* (Thomas Telford, London, 1998).
10. T. Sakai, K. Hatanaka, and T.H. Mase, "Wave Induced Stresses in Seabed and its Momentary Liquefaction," *ASCE Journal of Waterways, Port, Coastal and Ocean Engineering* **118**(WW2), 202-206, 1992.
11. P.J. Mulhearn, A Mathematical Model for Mine Burial by Mobile Underwater Sand Dunes, Aeronautical and Maritime Research Laboratory, Defense Science and Technology Organization, Melbourne, Victoria, Australia, 1996.
12. Version 2.0 Bottom Sediment Type Data Base, 2006, and Version 5.2 Digital Bathymetry Data Base, 2007. Naval Meteorological and Oceanographic Command: Stennis Space Center, MS.
13. H.L. Tolman, B. Balasubramaniyan, L.D. Burroughs, D.V. Chalikov, Y.Y. Chao, H.S. Chen, and V.M. Gerald, "Development and Implementation of Wind-generated Ocean Surface Wave Models and NCEP," *Weather and Forecasting* **17**, 311-333, 2002.
14. N. Booij, R.C. Ris, and L.H. Holthuijsen, "A Third-generation Wave Model for Coastal Regions. 1. Model Description and Validation," *J. Geophys. Res.* **104**(C4), 7649-7666, 1999.
15. A.V. Abelev, P.J. Valent, and K.T. Holland, "Behavior of a Large Cylinder in Free Fall through the Water," *IEEE J. Oceanic Engin.*, in press, 2007.
16. S. Theophanis, "Accelerometer and Fiber Optic Gyro Measurements of an Instrumented Cylinder Used to Study Impact Burial," *Proceedings of the IEEE/MTS Oceans 2002 Conference.*
17. T.F. Weaver and R. Lühder, "Impact Burial and Liquefaction Potential in Restricted Area Schönhagen, Western Kiel Bay – Research Cruise with MzB Mittlelgrund," Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik, Keil, Germany, June 10-13, 2003.

18. T.F. Weaver, R. Lühder, and I. H. Stender, "Burial Registration Mines – 30 Years of Seafloor Research," *Sea Technology* **45**, 15-19, 2004.

19. P.J. Mulhearn, "Experiments on Mine Burial on Impact – Sydney Harbour," *U.S. Navy Journal of Underwater Acoustics* **43**, 1271-1281, 1993.

20. M. Hollander and D.A. Wolfe, *Nonparametric Statistical Methods*, 2nd ed. (Wiley-Interscience, New York, 1999).

21. A.V. Abelev and P.J. Valent, "Impact Burial of Cylinders in Soft Marine Sediments," *Proceedings of ASCE Conference, Civil Engineering in the Oceans 6*, October 20-24, 2004.

22. A.V. Abelev and P.J. Valent, "Dynamics of Bottom Mine Burial in Soft Sediments: Experimental Evidence and Predictions," *Mine Countermeasures & Demining Conference, Asia-Pacific Issues & MCM in Wet Environments*, February 9-11, 2004.

23. T.C. Austin, J.B. Edson, W.R. McGillis, C. von Alt, M.J. Purcell, R. Petitt, M.K. McElroy, J. Ware, and R. Stokey, "The Martha's Vineyard Coastal Observatory: a Long Term Facility for Monitoring Air-sea Process," *Proceedings of the IEEE/MTS Oceans 2000 Conference*, 1937-1941.

24. S. Griffin, J. Bradley, and M.D. Richardson, "Improved Subsequent Burial Instrumented Mines," *Sea Technology* **44**, 40-44, 2003.

25. NCEP WaveWatch-III, retrieved June 2007, ftp://polar.ncep.noaa.gov/pub/history/waves/

26. SWAN, Version 40.41, Delft University of Technology, The Netherlands, 2004. http://fluidmechanics.tudelft.nl/swan/default.htm.

27. NOAA National Geophysical Data Center, retrieved June 2007, http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html

28. P.J. Caplan, W. Derber, S-Y. Gemmill, H.-L. Hong, H.-L. Pan, and D. Parish, "Changes to the 1995 NCEP Operational Medium-Range Forecast Model Analysis/Forecast System," *Weather and. Forecasting* **12**, 581-594, 1997.

29. M. Kanamitsu, J.C. Alpert, K.A. Campana, M.P. Caplan, D.G. Deaven, M. Iredell, B. Katz, H.-L. Pan, J. Sela, and G.H. White, "Recent Changes Implemented into the Global Forecast System at NMC," *Weather and Forecasting* **6**, 425-435, 1991.

30. R. Allard, J. Christiansen, T. Taxon, S. Williams, and D. Wakeham, "The Distributed Integrated Ocean Predicted System (DIOPS)," *Proceedings of the IEEE/MTS Oceans 2002 Conference*, 1234-1238.

31. R.M. Hodur, "The Naval Research Laboratory's Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS)," *Monthly Weather Review* **125**, 1414-1430, 1995.

32. N. Booji, J.G. Haagsma, L.H. Holthuijsen, A.T.M.M. Kieftenburg, R.C. Ris, A.J. van der Westhuysen, and M. Zijlema, 2004. SWAN Cycle III version 40.41 User Manual, Delft University of Technology, The Netherlands.

33. K. Hasselmann, T.P. Barnett, E. Bouws, H. Carlson, D.E. Cartwright, K. Enke, J.A. Ewing, H. Gienapp, D.E. Hasslemann, P. Kruseman, A. Meerburg, P. Müller, D.J. Olbers, K. Richter, W. Sell, and H. Walden, "Measurements of Wind-Wave Growth and Swell Decay during the Joint North Sea Wave Project (JONSWAP)," *Dtsch Hydrogr. Z., Suppliment* **12**(A8), 1973.

34. R. Allard, W.E. Rogers, S.N.Carroll, and K.V. Rushing, "Validation Test Report for the Simulating Waves Nearshore Model (SWAN): Cycle III, Version 40.11," Naval Research Laboratory, Stennis Space Center, MS, 2004.

35. R.C. Ris, L.H. Holthuijsen, and N. Booij, "A Third-Generation Wave Model for Coastal Regions. 2. Verification," *J. Geophys. Research* **104**(C4), 7667-7681, 1999.

36. S. Rennie, A. Brandt, and N. Plant, "A Probabilistic Expert System Approach for Sea Mine Burial Prediction," *IEEE J. Oceanic Engin*., in press, 2007.

Appendix A
SOFTWARE REQUIREMENTS AND INSTALLATION

A1.Platform Requirements

To run DMBP, the target platform must have the following specifications:

1. Use Microsoft Windows 2000 or later operating system
2. Mathworks MATLAB Version 7.0.4 or later (Recommended: Version 7.3 – a.k.a 2006b – as this version fixed a rendering bug of GUI controls when used in Windows XP. The Mapping Toolbox also may be installed for full functionality; it provides a small amount of additional, but nonessential mapping products.)
3. DVD-ROM drive
4. At least 512 MB of RAM (1 GB recommended)
5. At least 5 GB of free hard drive space (10 GB recommended)

A2. Installation Instructions

It is recommended that the software be placed in top-level C:\ directory in the folder C:\DMBP. All subsequent discussions make this assumption. The installation steps are as follows:

1. Place DVD in the DVD-ROM drive
2. Double click on the D:\DMBP.zip file and in the "Unzip to Folder" input box, type in "C:\" (assuming that the DVD drive is D:\ and the target directory is C:\). After the expansion of the compressed files is complete, there should be a C:\DMBP directory.

A3. File Structure

When the installation procedure as described in Section A2 is complete, the following directories should be installed:

1. C:\DMBP: This is the home directory for the software. It contains:
   a. \DMBP_src: source code
   b. \User_examples: files and data for running test cases
   c. Run_DMBP.m: start-up MATLAB script for the program

2. C:\DMBP\DMBP_src: This directory contains source code, geotechnical databases, and supporting files. The contents are as follows:
   a. \dbdbv_4.3: Version 4.3 of Digital Bathymetry Database – Variable resolution, Build 0 (which is approved for public release).
   b. \Impact_35: The IMPACT35 model
   c. \MakeTPARfiles: scripts for creating wave height and wave period input data from archived WaveWatch-III files that are available for download from the National Oceanic and Atmospheric Administration (NOAA).
   d. \Sediments: Version 2.0 of the Sediments database.
   e. runSediments.class and runSediments.java: Java files used by DMBP to automate data extraction from the Sediments 2.0 database.

f. DMBP.fig and DMBP.m: The GUI controls and source code files, respectively, for DMBP.
g. ConvertGRIBoutfile.m, i35batch.m, Liquefaction.m, ScourPf.m, SubsequentBurial.m, tabpanelfcn.m, yxz2mtx.m: Other M-files used by DMBP.

Appendix B
USERS' GUIDE

B1. START-UP

To run DMBP, the user must first start a MATLAB session and change the working directory to C:\DMBP. Then, type "Run_DMBP" at the command line to begin the software. The initial screen should appear (Fig. B1).

B2. OVERVIEW OF GUI CONTROLS

The different GUI groups discussed below are activated by mouse clicking on the tabs at the top of the DMBP GUI.

B2.1 Ocean Data

The opening set of controls (Fig. B1) specifies the location of bathymetry and sediment data files for ingest into DMBP. There are two basic operations: a) extraction and ingest of these data from NAVOCEANO DBDB-V 4.3 and Sediments 2.0 databases and b) creation of a hypothetical flat or sloped bathymetry with two different types of sediment types.

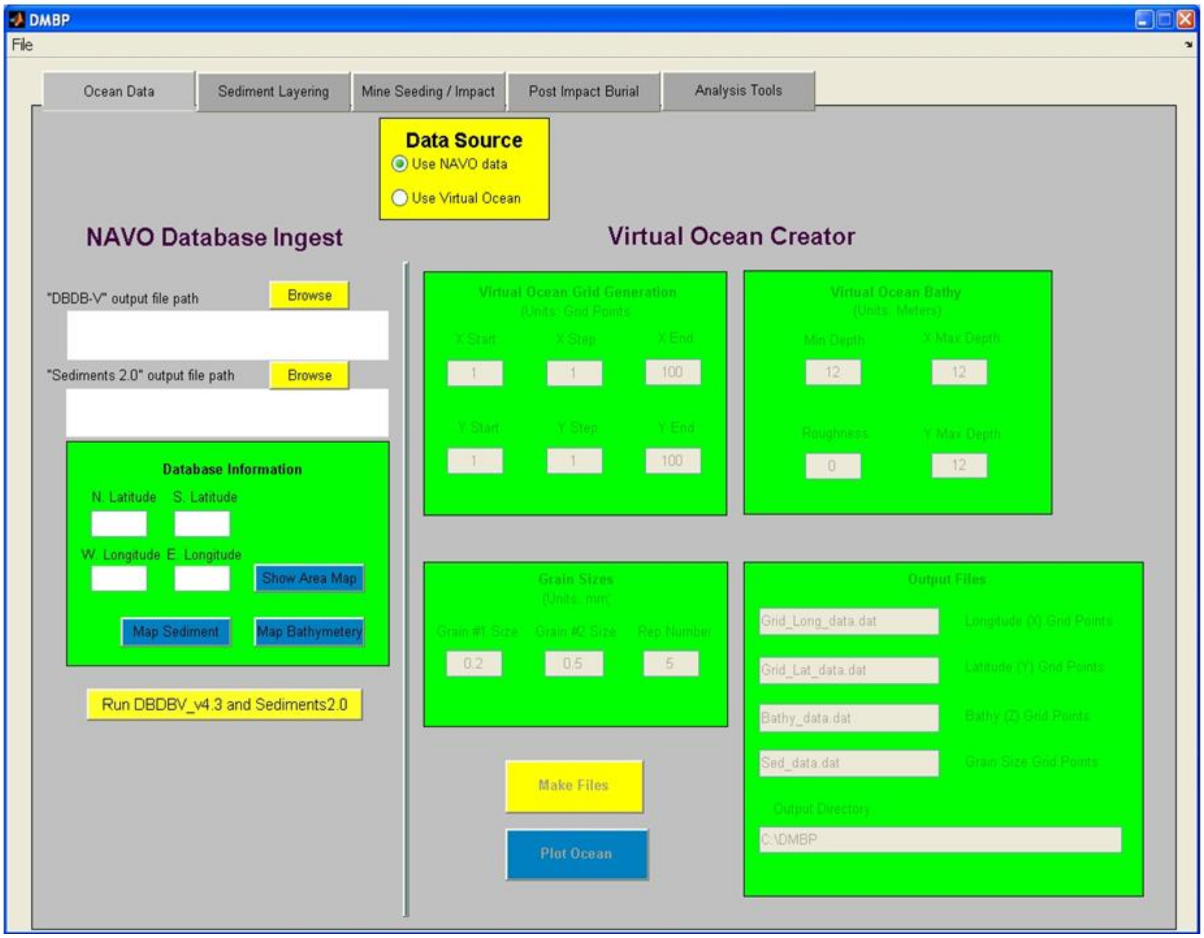


Fig. B1 – “Ocean Data” controls and initial screen of DMBP

a) To use NAVOCEANO data, click on the “Use NAVO data” radio button in the “Data Source” section, located near the top of the window. When this radio button is chosen, the GUI controls under “NAVO Database Ingest” will activate (these settings are set at start-up). The user may either specify the location of bathymetry and sediment files (file format requirements discussed later) or run the DBDB-V GUI to extract these files from the databases. To specify the location of the files, click on “Browse” above each path window to navigate to the files and select them. To extract them from the databases, click on the “Run DBDB-V_v4.3 and Sediments2.0” pushbutton, and then follow the directions in Section C.1 below. After DMBP ingests both files, the bounding coordinates will appear in the “Database Information” section. Either the “Map Bathymetry” or “Map Sediment” pushbuttons plots the data in a MATLAB figure window. If the Mapping Toolbox is installed, the “Show Area Map” will plot the area from world vector shoreline data that accompanies the Toolbox.

To use a hypothetical water column with a flat or sloped bottom, click on the “Use Virtual Ocean” radio button in the “Data Source” section, located near the top of the window. After clicking on this radio button, the GUI controls under “NAVO Database Ingest” will activate (Fig. B2), and the controls under “NAVO Database Ingest” become inactive.

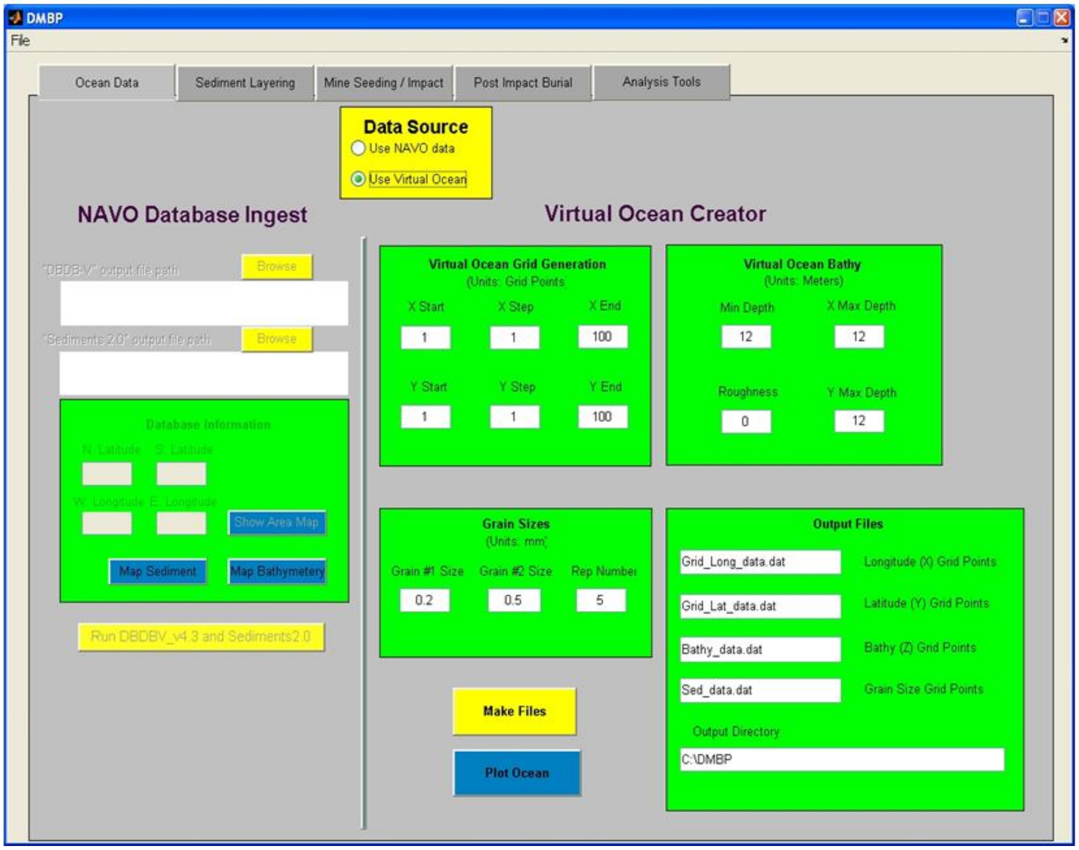


Fig. B2 – Virtual Ocean GUI controls. This set of controls is under the Ocean Data tab and activated by clicking on the "Use Virtual Ocean" radio button.

Four groups of edit boxes and two pushbuttons are used to create the computational grid.

i. "Virtual Ocean Grid Generation" fields: These edit boxes specify the number of grid points to generate for a two dimensional (X,Y) grid. All numbers should be positive integers. "X Start" and "Y Start" are the starting indices for the X and Y dimensions; both should be set to 1. "X Step" and "Y Step" are the grid increments; for uniform grids, both should be set to 1. Set one of these numbers to some other integer greater than 1 for nonuniform grids. "X End" and "Y End" specify the ending grid point index. For uniform grids, these values specify the total number of grid points for either direction. For nonuniform grids, the numbers should be set so that the final indices fall on a grid node (e.g., for a "X Start" = 1 and a "X Step" = 2, "X End" = 51 for 25 grid points in the X direction).

ii. "Virtual Ocean Bathy" fields: These controls specify the bottom slope and roughness; all boxes use positive integers. "Min Depth" sets the minimum depth of the bottom. "X Max Depth" and "Y Max Depth" specify the maximum depths in the X and Y directions, respectively. For a flat bottom, set these values equal to the "Min Depth" setting. For a slope in one direction, set the appropriate Max Depth control to the desired maximum depth. Setting both to different values provides a bottom with different slopes in the X and Y directions. Setting "Roughness" to a nonzero value adds normally distributed fluctuations to bathymetry at node points. The standard deviation of the fluctuations is the number specified in "Roughness."

iii. “Grain Sizes” fields: These controls allow for strips of two different grain sizes to be allocated along the virtual seafloor. Specify the desired grain sizes in millimeters in the edit boxes under “Grain #1 Size and “Grain # 2 Size” (for a uniform floor, set both to the same value). “Repetitions” sets the number of times to repeat the pattern along the seafloor in the Y direction (for a uniform floor, set this value to 1). Make certain that the number of repetitions divides evenly with the number of grid nodes in that direction.

iv. “Output Files” fields and “Make Files” pushbutton: After grid generation, the program can store gridded latitude, longitude, bathymetry and sediment data to files, as specified in the appropriate edit boxes, on the hard disk in the directory specified in the “Output Directory” edit box (default is C:\DMBP\). Storage occurs after clicking the “Make Files” pushbutton.

v. “Plot Ocean” fields: A preview of the hypothetical ocean bottom grid and grain distributions appears in a new figure window after clicking this pushbutton.

B2.2 Sediment Layering

The impact module requires value of bearing strength (in Pascals) and density (in kg/m^3) of the sediment. In the “Sediment Layering” GUI control group (Fig. B3), the user specifies these values at different depth intervals (up to 20, in units of meters) in the sediment. Also specified here is the percentage of air content in the sediment which is used for prediction of burial by liquefaction (default is zero).

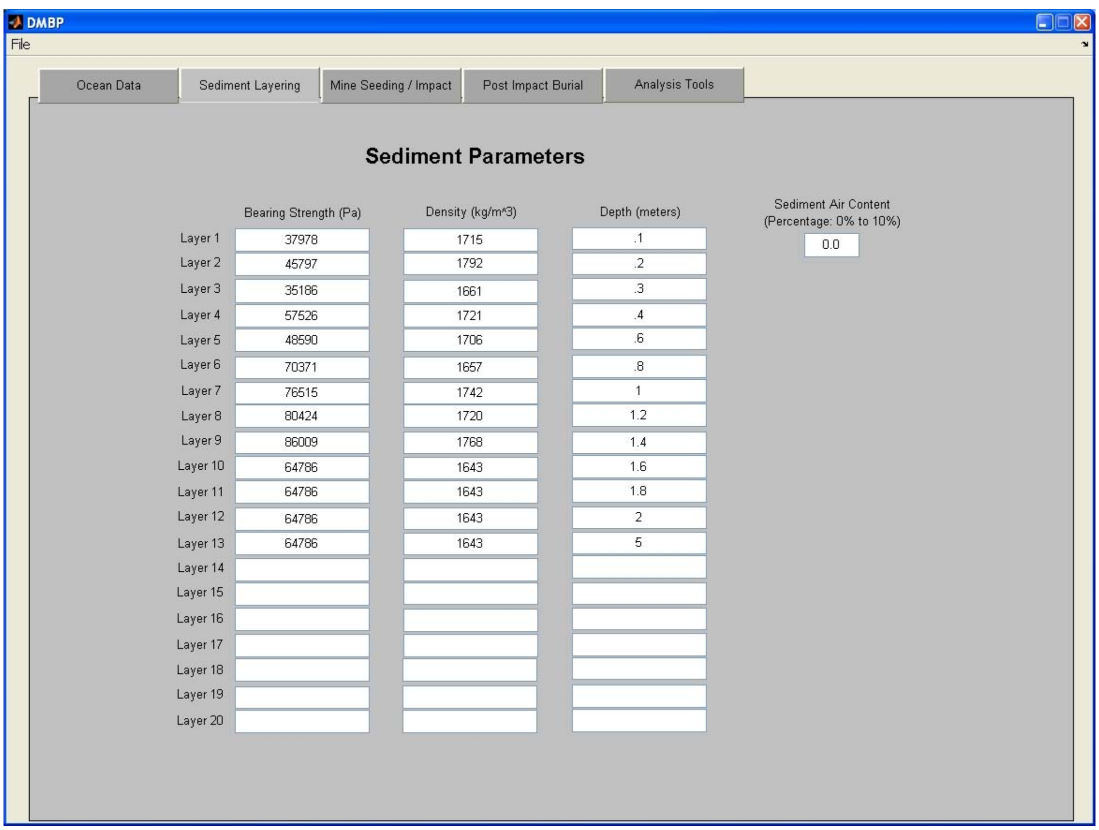


Fig. B3 – Sediment Layering GUI group

B2.3 Mine Seeding / Impact

The impact model also requires information on the geometric, inertial and kinematic properties of the mine at release, as well as water temperature and density for buoyancy considerations. The user specifies these properties under this GUI group in the appropriate user entry boxes (Fig. B4). Assuming cylindrical or tapered cylindrical geometries, the properties specified here in the corresponding edit boxes (in the two columns marked "Value") are as follows (in MKS units).

- Mass of mine
- Length: total end-to-end length
- Diameter: diameter about the geometric center
- Taper Length: if the mine has a tapered end, this is the taper length at one end
- Taper Diameter: the minimum diameter at a tapered end
- Distance from the center of geometry to the center of mass: often, the center of mass is not at the geometric center. This field specifies the offset between the two.
- Initial Vertical Velocity: initial center of mass velocity normal to the water surface
- Initial Horizontal Velocity: initial center of mass velocity parallel to the water surface
- Fall Angle: zero degrees means the axis of symmetry is parallel to the water surface
- Rotation rate: Maximum rate of 360 degrees per second allowed
- Water Temperature
- Water Density
- Altitude: Release height above the water. Negative altitudes are underwater releases.

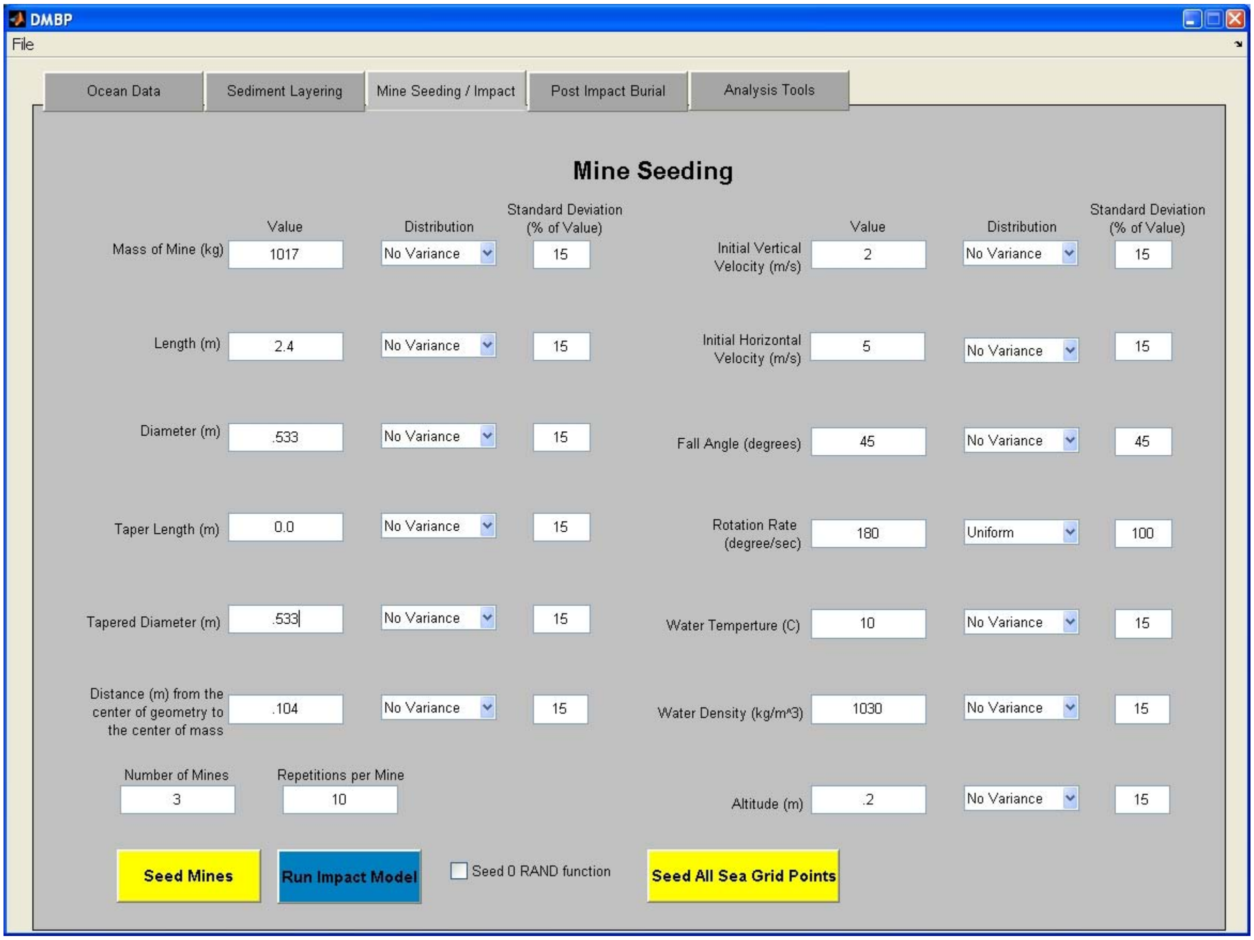


Fig. B4 - Mine Seeding / Impact GUI group

Each of these values can be varied from one mine drop to the next by adding normally or uniformly distributed variations to these parameters by choosing one of the options from the adjacent drop-down menus (default is no variation). The user specifies the amount of scatter in the edit box to the right of the drop-down menu. For normal distributions, this number becomes the distribution's standard deviation as a percentage of the number in the corresponding "Value" edit box. For a uniform distribution, this number sets the upper limit by adding this percentage of the value to itself and the lower limit by subtracting this percentage of the value from itself.

The edit boxes "Number of Mines" and "Repetitions per Mine," respectively, specify the number of latitude-longitude positions seeded in the area of interest and how many times a drop will be repeated at each latitude-longitude position for Monte Carlo simulations of impact burial. The "Seed Mines" pushbutton seeds the mines at random, non-land node points of the computational grid. The "Seed All Sea Grid Points" seeds all non-land node points with mines. If the use of the same sequence of random numbers is desired during Monte Carlo simulations for control purposes, activating the "Seed 0 Rand Function" will reset the MATLAB random number generator to its initial state before each simulation.

Once all mine seeding is complete, clicking on the "Run Impact Model" executes the impact module. The MATLAB command window will display impact burial result for each individual simulation. A

progress bar also appears to give the end user a visual gauge of the total progress for the overall simulation.

NOTE: If only burials by subsequent burial processes are to be calculated, running the impact burial model is unnecessary. In this case, the end user only needs to a) specify mine diameter and the number of mines to seed and b) click on either the "Seed Mines" or "Seed All Sea Grid Points" pushbuttons.

B2.4 Post-impact Burial

This GUI group (Fig. B5) controls calculations of burial due to scour, liquefaction and sand-ridge migration. NOTE: Mine diameter specification and seeding must be done first before performing subsequent burial predictions. Any one, two or all three of these processes may be activated by clicking the appropriate checkbox in the "Subsequent Processes to Use" section.

The initial burial state of the mines can be obtained by running the impact simulation first or simply assuming an initial percentage of burial. These choices are made in the "Use Initial Impact Burial" section. To use initial burial states from the impact simulations, click on the "Yes" radio button. The "Impact Burial File" and "Mine Locations File" edit boxes are filled with the default files that store mine burial state and position output files from the burial module. To assume a common initial burial depth, use the "No" radio button. The "Initial % Burial" edit will become active to set initial burial depth as a percentage of mine diameter. The default value is 10%. (Note: Under normal situations where scour, sand ridge, or liquefaction burial will occur, the sediments will be predominately sand and impact burial will be 10% or less [5].)

The wave-induced scour and liquefaction burial models require the following gridded time-series data: a) wave period, and b) significant wave height. Current-induced scour and sand-ridge migration require c) gridded time-series current data. All processes need gridded d) water depth and e) mean grain size. The user specifies the location of the files in the "Oceanography Data Files to Use" section. The time series oceanographic data are derived from either SWAN or WaveWatch-III simulations or from actual observations. To activate this section, click on the "Use Time Series" radio button. The location of the following data file are then provided by either clicking on the neighboring "Browse" pushbutton to select the file from a file selection GUI or by manually typing in the full path and filename.

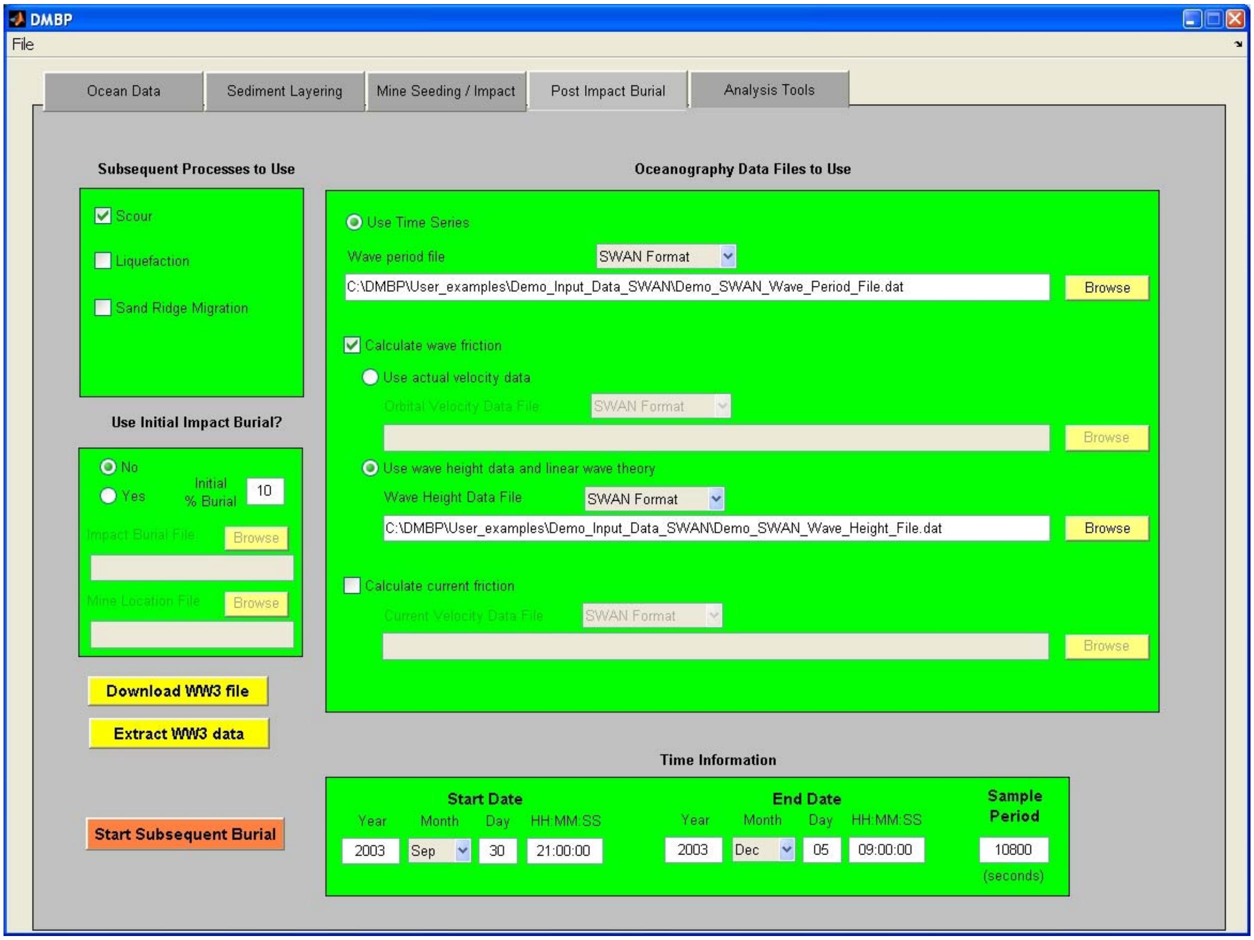


Fig. B5 – Post Impact Burial GUI control group

- Wave period data: provided by the file in the “Wave period file” edit box. Active by default.
- Wave friction data: Activated by clicking on the “Calculate wave friction” checkbox. Wave friction ([8], Eq. 61) is determined with one of two methods for providing orbital velocity.
  - “Use actual velocity data” radio button: use actual orbital velocity data (in m/s) as provided by the file in the “Orbital Velocity Data File” edit box.
  - “Use wave height data and linear wave theory”: use significant wave height data (in meters) as provided by the file in the “Wave Height Data File” edit box and translate this quantity into orbital velocity (in m/s) using linear wave theory ([8], Ch. 4].
- Current friction data: provided by the file in the “Current Velocity Data File” edit box. This set of controls is activated by clicking on the “Calculate Current Friction” checkbox. The current friction data is just magnitude (in m/s). An average direction of 45 degree is assumed to exist between this current and the orbital current. Coupling between the two uses the approach given in Whitehouse ([9], Appendix 2).

The user specifies if the data is two-dimensional gridded data by choosing the “SWAN Format” option from the drop-down menu or is one-dimensional time series data by choosing the “MAT-File” option. If the MAT-file option is chosen, the program will create two-dimensional gridded data from it by reproducing the time-series at each non-land grid point.

Once the names of the input data files are in the DMBP GUI, the user needs to specify the start and end time of the simulation and the sample period in the “Time Information” section. For the edit box controls under both “Start Time” and “End Time”, the end-user type in the follow information: the “Year” is given in four digits, the “Day” in two digits (e.g., the third day of the month is entered as “03”) and clock-time in “HH:MM:SS” 24-hr format. The month is selected from the drop-down menu. The period between time steps of data is entered manually in seconds in the “Sample Period” edit box. <u>NOTE: Since only one set of start times, end times, and sample periods are used, all input data should have the same number of time steps.</u>

Clicking on the “Start Subsequent Burial” pushbutton will start the subsequent burial calculations. Before the modules execute, a popup window appears that prompts the user to enter information about the oceanographic input data: a) the southwest origin for the latitude and longitude, b) the latitudinal and longitudinal grid spacing in degrees, and c) the number of latitudinal and longitudinal grid points. Clicking “Cancel” in this window will return the user to the DMBP GUI.

The “Download WW3 files” and “Extract WW3 data” push buttons provide the user with capabilities to download WaveWatch-III data from NOAA if SWAN data or a 1-D Time-series area unavailable. Directions for using these controls are in the “Scour Burial Using WaveWave-III Data” walkthrough example.

B2.5 Analysis Tools

This GUI control group (Fig. B6) provides the user with visualization and mapping tools to analyze the burial predictions. Directions for using these controls are in the “Impact Burial Simulation” and “Scour Burial Using SWAN Data” walk-through examples.

B2.6 File Menu

The “File” menu (Fig. B7) in the upper left of the DMBP window allows the end-user to save information entered into the DMBP GUI to a MATLAB MAT-file from the “Save Setting to File” option. These settings may be reloaded with the “Load Settings from File” option. Both open a file navigation GUI where the user can search through directories and specify the name of the MAT-file for saving or retrieving GUI settings. Similarly, computational results may be saved and reloaded without having to rerun the simulations by choosing the “Save Data Run to File” and “Load Data Run from File” options. The walk-through examples below make extensive use of these features. In addition, sediment data may be uploaded into DMBP by choosing the “Import IMPACT35 Sediment File” option. The “Exit” option closes DMBP and returns the user to the MATLAB Command Window.

Fig. B6 – Analysis Tools GUI control group

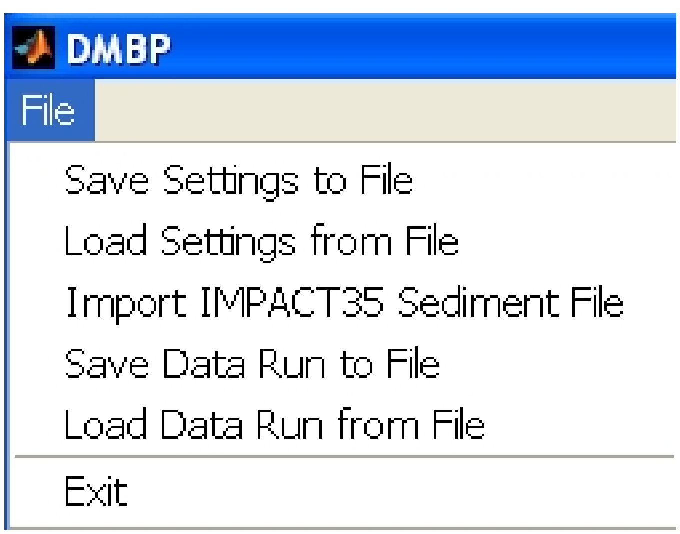


Fig. B7 – “File” menu GUI

Appendix C
TEST CASE WALKTHROUGHS

The following walkthroughs will acquaint the end-user with the functionality of DMBP and steps to run their own simulations. The instructions assume that the user is familiar with navigating in the Windows operating system environment and is using a mouse. The walkthroughs after Section C1, which provides instructions on loading bathymetry and sediment data, assume that these data have been loaded into the program.

C1. DBDB-V AND SEDIMENTS DATA EXTRACTION

a) Click on the "Ocean Data" tab if it is not active. Then click on the 'Run DBDBV_v4.3 and Sediments 2.0' pushbutton. This action will first bring up a GUI that prompts the user to select a directory for storing the output bathymetry and sediment files. For now, choose "C:\DMBP\User_Examples\." Once selected, a java routine will run to startup the DBDB-V GUI (Fig. C1). Click "OK" on the subsequent database locations and the distribution statement GUIs to get to the DBDB-V GUI. Once it is running, click on the "Area" tab in the GUI. In this exercise and the rest that follow, the area of interest is the Martha's Vineyard and Cape Cod region. Type in the following coordinates into the "Top," "Bottom," "Left," and "Right" text boxes: "N 41.5," "N 41," "E -71," and "E -70." (Alternately, a user can click on the "Zoom In" button underneath the world map to zoom in to a region with an interactive rubberband box.) Set the "Spacing (In Minutes)" text box to "0.1" (this is the highest resolution of bathymetry that should be extracted with the DBDB-V software.) Leave the "Coordinate System" at "Equatorial." Also, under the "Extraction Properties" tab, the "depths sign" should be at "positive depths."

b) Click on "Submit." An input dialog box titled "Area Output Options" appears. Click on the second to the bottom option, "YXZ." The input text box to the right activates. Type in the name desired for the file, but leave the ".yxz" suffix. For now, use the default "Bathy1.yxz." Click "OK" at the bottom of the box. A confirmation dialog appears. Assuming the input parameters are correct, click "Yes." Data extraction begins. When completed, a confirmation dialog appears. Click "Close," then exit the DBDB-V GUI by clicking the standard dismissal button at the top right of the GUI.

c) Once the DBDB-V GUI closes, click "OK" in the MATLAB dialog box that says, "When you are done with DBDB-V click 'OK'." An input dialog box then appears with the instruction, "Enter the name of your DBDB-V Bathymetry file." Type in the exact same name used in the DBDB-V GUI from step b) above. The default is "Bathy1.yxz." Click "OK" once you are done, or "Cancel" to start over if necessary.

d) A message box appears, "If it is on, you MUST turn the "CAPS LOCK" key OFF. Check to make sure the "Caps Lock" key is not activated on the keyboard, then click "OK.""

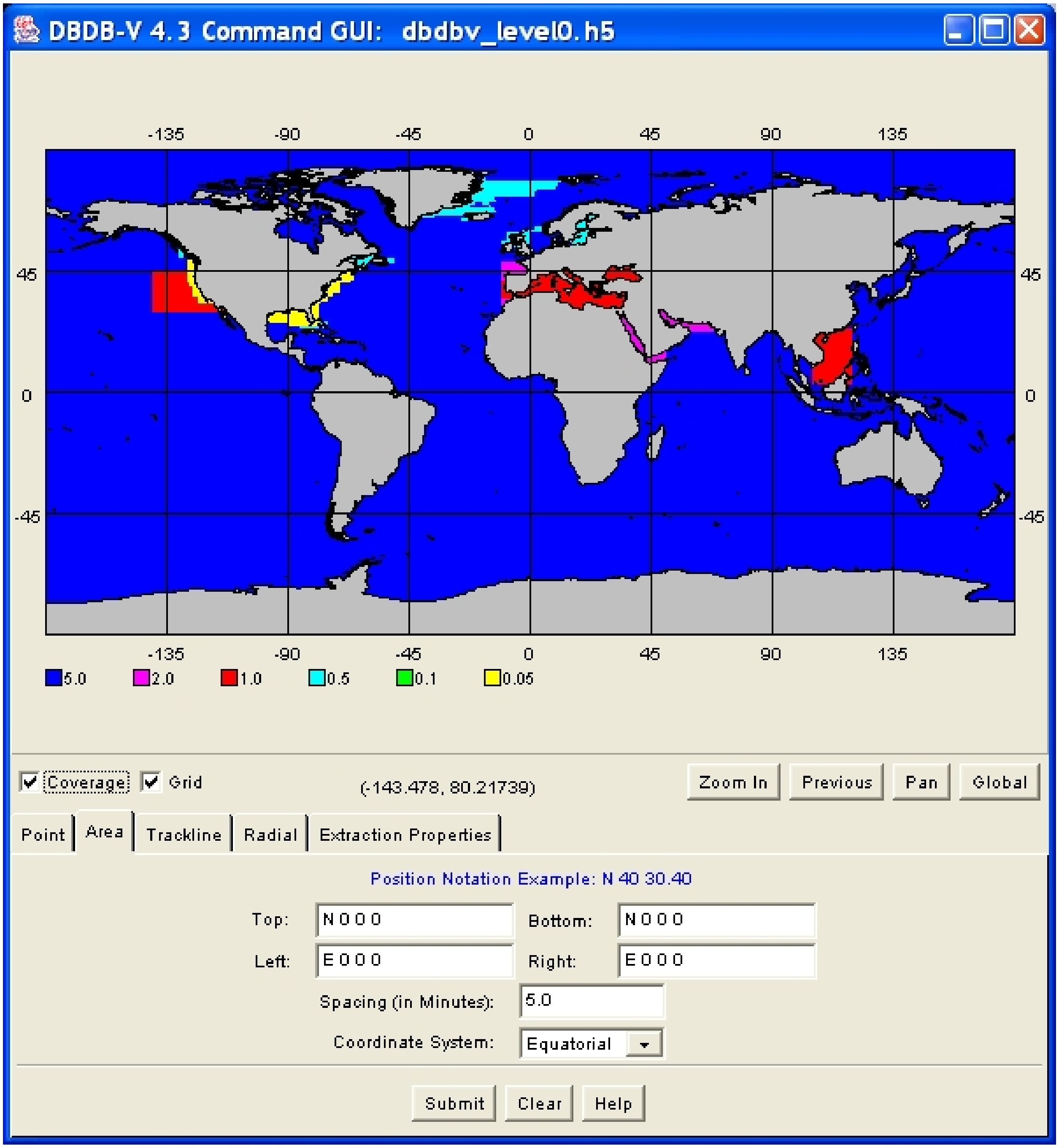


Fig. C1 – DBDB-V GUI. "Area" control group activated.

e) A java program will then run in a command window to automatically extract sediment data from the Sediments 2.0 database. When the command window disappears, click "OK" in the dialog box, "When Sediments 2.0 is finished please click "OK."" Repeat this process for the next two dialog boxes – there may be a delay between clicking on the second box and seeing the third one appear.

f) An input dialog box will then appear, asking for the name of the Sediments 2.0 output file. This file name may be changed as desired, but leave the "*.s" suffix. The default name is "data1.s." After designating a file name, click "OK."

g) The bathymetry and sediment data should be loaded into computer memory. Under the "Ocean Data" tab of DMBP, the ""DBDB-V" output file path" and ""Sediments 2.0" output file path" boxes should be displaying the full path names to the DBDB-V and Sediments 2.0 output files. Also, the bounding coordinates for the region should be displayed in the "Database Information" portion of the DMBP GUI. Click on either "Map Bathymetry" or "Map Sediments" to see a map of either data set. Click on "Show Area Map" for a map of the region if the Mapping Toolbox is installed.

C2. IMPACT BURIAL SIMULATION

Impact burial relies on specification of bearing strength and sediment density as a function of depth. The user specifies these parameters under the Sediment Layering tab. To work with the provided example, "Impact1," perform the following steps.

a) Choose "Load Settings from File" from the "File" menu. Navigate to "C:\DMBP\User_examples\Impact_1_Demo\" and choose "Impact1_Settings.mat." Fields in the "Ocean Data" and "Sediment Layering" window should fill with data and path names to data files.

b) Click on the "Mine Seeding/Impact" tab to switch to that GUI group. Parameters for mine geometry, inertia, and initial kinematic conditions should be present after loading the "Impact1_Settings.mat" file.

c) Note that the "Number of Mines" number is 3 and the "Repetitions per Mine" is 10. Change these numbers if desired (note that the impact module can take a long time to run even one prediction depending on the speed of your PC). Click on "Seed Mines" to place mines randomly in the region of interest. The program will display a progress bar as the seeding progresses. In order to reproduce the seeding locations for each simulation, click the "Seed 0 RAND function" checkbox before seeding the mines to reset the random number generator to its initial state each time. The positions of the mines may be plotted before running the impact module by clicking on the "Analysis Tools" tab and then clicking on the "Sediment" or "Bathymetry" pushbuttons in the "Map Mine Positions" section. A new figure window appears with the mines plotted on top of the sediment or bathymetry data. (If the Mapping Toolbox is installed, clicking on "Area Map" plots the mines on a shoreline map.)

d) To begin the impact simulations, click on "Run Impact Model." As the simulations run, DMBP displays and updates a progress bar. In addition, the Command Window will show percent burial for each simulation and the mean exposure of each mine after all simulations are complete. Alternatively, one may load the data file that provides the results of this simulation by choosing "Load Data Run from File" from the "File" menu, navigating to the "C:\DMBP\User_examples\Impact_1_Demo\" directory and choosing "Impact1_Settings.mat."

e) After the calculations are complete, click on the "Analysis Tools" tab. On the "Plot Controls," choose "Scatter Plot." In the "Impact Burial" box, choose "Mean Burial" from the drop-down menu. Then, click on the "Area Plot" pushbutton to produce a scatter plot of the area of interest with plot symbols color-coded to indicate mean burial. (Choosing "Median Burial" or "Standard Deviation" in the drop-down menu will produce similar plots for those quantities.)

f) In the scatter plot map, the standard MATLAB figure toolbar is present at the top of the map. In that toolbar, choose the “Data Cursor” tool. The mouse icon will change from an arrow to vertical cross. Click on one of the data points to display the longitude (X) and latitude (Y) for the data point; the Z coordinate shows percent volume burial divided by 10 (scaling performed to get plotting to work properly). Manually enter the latitude and longitude for this data point into the “Latitude” and “Longitude of Mine” edit boxes, then click on the “Plot Statistics” pushbutton. A new plot window appears, showing two plots. The top graph is percent volume burial for each repetition at that location. The bottom graph is running mean, median, and standard deviation of percent volume burial as a function of repetition number.

g) A second set of impact simulations is in the “C:\DMBP\User_examples\Impact_2_ Demo\” directory. It provides data for softer sediment so that more burial occurs. This simulation is run in the same manner as discussed above.

C3. SCOUR BURIAL USING SWAN DATA

Scour burial relies on gridded time series data for significant wave height and peak wave period. The user specifies the location of data files providing this information under the “Post Impact Burial” tab. These data may come from either SWAN or WaveWatch-III wave models. To work with the provided example for SWAN, do the following.

a) Choose “Load Settings from File” from the “File” menu. Navigate to “C:\DMBP\User_ examples\Scour_SWAN_Demo\” and choose “SWAN_Settings.mat.” Fields in the “Ocean Data,” “Sediment Layering,” “Mine Seeding / Impact,” and “Post Impact Burial” should fill with data and path names to data files.

b) Click on “Mine Seeding / Impact.” Note that the “Number of Mines” field is set at “5000,” and the “Repetition per Mine” is set at “1.” Only one mine is necessary per location because initial burial for all mines will be 10%. Click on “Seed Mines” to place mines at random locations in the region of interest. As with the impact simulations, the program will display a progress bar as the seeding progresses, and to reproduce the seeding locations for each simulation, click the “Seed 0 RAND function” checkbox before seeding. As with the Impact simulations, mine position may be plotted from the “Map Mine Positions” controls in the “Analysis Tools” tab.

c) Once the mines are seeded, click on the “Post Impact” tab. Critical GUI settings to note are as follows:

   i. The “Use Initial Impact Burial?” box is set at “No” and that the “Initial % Burial” is set at “10,” meaning all mines have an initial burial of 10%. This setting is meaningful in sandy environments since impact burial does not occur, and a nominal 10% burial from settling may be assumed [5]. Burial states from the impact module, however, may be used by running the impact module first (c.f. Section 4.C.2 above) and then clicking on “Yes” in this box (leave the file names in the box as-is when they appear).

   ii. The scour checkbox is active in the “Subsequent Processes to Use” section, indicating that scour burial alone will be calculated.

iii. In the "Time Series to Use" section, the full paths for wave period and wave height data are given in the "Wave period file" and "Wave Height Data File" edit boxes. The latter box is activated by clicking on "Calculate wave friction" checkbox and the "Use wave height and linear wave theory" radio button. The drop-down menus for both are set at "SWAN Format" to set the expected format to be the SWAN output format.

iv. The temporal information – start time, end time, and time step in seconds – corresponding to the SWAN input data are set in this section. The "Year" in four digits, "Day" in two digits and times in "HH:MM:SS" twenty-four hour format for both are entered into the appropriate edit boxes and the month is selected from the dropdown menu. In addition, the period between time steps in seconds is entered in the "Sample Period" edit box. Note that 10800 seconds equals three hours.

d) Once these settings are uploaded to the DMBP GUI, click the "Start Subsequent Burial" pushbutton to begin the burial module calculations. Before the burial module executes, the popup window will appear to prompt the user to specify computational grid parameters used in the SWAN simulation. The default settings correspond to the SWAN files used, so simply click "OK." Clicking on "Cancel" aborts the calculation and returns the user to the DMBP GUI.

e) As the scour module proceeds, the program will display and update a progress bar that disappears when the calculations are complete. After the calculations are complete, click on the "Analysis Tools" tab. The "Plot or Movie Start Time," "Movie End Time," and "Plot Control" sections are active with "Color Image" chosen. Move the slider bar under "Plot Movie or Start Time" until the temporal display above it reads "2003 10 06 00:00:00"; alternatively, you can manually change the text in these edit boxes from the keyboard – the slider bar will automatically adjust position to correspond to this time. Then, click the "Map Burial For This Time" pushbutton. A color map of the burial for this time will appear in a new figure window. A scatter plot also is displayable by clicking the "Scatter Plot" radio button, but we do not recommend this action because a large number of points will be plotted, and MATLAB can take a long time to perform this action

f) A movie of the evolving burial also can be made in AVI format. Move the slider bar in the "Plot or Movie Start Time" section to the beginning (far left position) and move the slider bar under "Movie End Time" to "2003 10 11 00:00:00" (or manually type this information into the edit boxes). Click on the "Make Movie" pushbutton. A new figure window will appear that will step through each burial plot for each time step of the SWAN input data. <u>Make sure that no other window is placed on top of this figure or else that window will appear in the movie.</u> After the last time step is reached, the movie can be displayed in a media player (such as Windows Media Player, Winamp, etc.) The movie name is "movie2_i5_50.avi" and is in the "C:\DMBP\DMBP_src\" directory. It needs to be moved and renamed in Windows if you want to keep it. A provided example file is in "C:\DMBP\User_examples\Scour_SWAN_Demo\ movie2_i5_50.avi."

C4. Scour Burial Using WaveWatch-III Data

This example shows how to use WaveWatch-III for the wave data instead of SWAN (it is assumed that the user has gone through the previous walkthrough above). With SWAN, an independent SWAN

simulation needs to have been set-up and run *a priori* for the area of interest. If this requirement is unobtainable, DMBP can provide the user with internet access to the NOAA ftp site to download WaveWatch-III data. After obtaining data for the time period of interest, DMBP can further extract the area of interest from the archive (which is in Gridded Binary (GRIB) format) and create input files for the ingest into the scour module. The resultant input file is in the same format as the SWAN data with three-hour time-step intervals.

a) Choose "Load Settings from File" from the "File" menu. Navigate to "C:\DMBP\User_examples\Scour_WW3_Demo\" and choose "WW3_Settings.mat." As before, fields in the "Ocean Data," "Sediment Layering," "Mine Seeding / Impact," and "Post Impact Burial" should fill with data and path names to data files. Click on "Map Bathymetry" in the "Database Information" section of the "Ocean Data" tab. Notice that the area around the Martha's Vineyard is expanded to a 1-degree by 1-degree box. The coverage will allow use of a 5 by 5 computational grid with the WaveWatch-III data.

b) Follow directions for seeding the mines as described in Section C3.b above.

c) You will now get archived WaveWatch-III data and extract data for the area of interest into input files for DMBP. These wave height and period files that are created for driving the scour module will use the same file format as the SWAN data.

   i. Click on the "Post Impact Burial" tab after seeding the mines. Then, click on the "Download WW3 file." A warning dialog appears that instructs you to place the files you download into separate folders that you need to create in Windows. The next dialog box prompts the user to confirm the URL for the WaveWatch-III FTP archive. As of this writing, the default URL is current, so click "OK" (or change it to a new URL if needed).

   ii. The default web browser for the PC will open at the URL specified above. Click on the "README" file to familiarize yourself with the contents. We will need to download wave height and wave period files from this archive for the Western North Atlantic region for January 2003. For convenience, these files for all of 2003 are in "C:\DMBP\User_examples\Demo_Input_Data_WW3\gribfiles\200301\." Find the file "wna.hs.200301.grb." (The parts "wna," "hs," and "200301" indicate Western North Atlantic, significant wave height, year, and month; the .grb suffix indicates that the file is a GRIB archive.) Download this file to a convenient directory on your PC. Repeat this download process for the corresponding wave period file, "wna.tp.200301.grb." Once the files download to the PC, you can close the web browser.

   iii. Click on "Extract WW3 data." A GUI appears, "Browse For Folder," that instructs you to navigate to and select the directory containing your GRIB files. Click on "OK" when you select the appropriate directory. A new window then appears showing the directory contents (in case you picked the wrong directory, you can navigate to the appropriate one in this GUI). Pick the appropriate GRIB file(s) corresponding to the wave height. You can select multiple files by holding down the "Shift" key on the keyboard to select contiguous files or the "Cntl" key to select non-contiguous files. For now, select "wna.hs.200301.grb" and click "OK." Repeat this process for the next GUI, prompting you to select wave period GRIB files; choose "wna.tp.200301.grb." Note that if you want to abort this process and return to the DMBP GUI, you may click "Cancel" in any of the popup GUIs.

iv. A GUI will then appear asking for confirmation of the WaveWatch-III grid spacing. Use the default 0.25 degrees for Western North Atlantic data; click "OK." Afterwards, a second GUI appears asking for confirmation of which WaveWatch-III data set you are using; use the default value of "1" for the Western North Atlantic.

v. A set of popup menus appear asking you to select a file name and directory location for the extracted wave height and period data. This output data will be in ASCII format; leave the suffix of the file as ".txt." Navigate to the directory of your choice and choose a convenient output file name for the wave height file. Repeat this process for the wave period file. Examples in the "C:\DMBP\User_examples\Demo_Input_ Data_WW3\" directory are "Demo_WW3_Wave_Height_File.txt" and "Demo_ WW3_Wave_Period_File.txt." As the data are extracted, a progress bar appears showing the file being extracted and the progress made toward extraction. Progress dialogs also appear in the MATLAB Command Window as the output from the executable performing the data extraction is displayed for each time step of the file.

d) After creating the input files from the WaveWatch-III archives, type in the full path names to the appropriate file in the "Wave Period File" and "Wave Height Data File" edit boxes in the "Post Impact Burial" tab or search for them by clicking on the "Browse" pushbutton above each edit box. Enter the correct temporal information of the wave data in the "Time Information" section as discussed in Section C3.c.iv above. The files start at 00:00:00 of the first day of the first month and end at 00:00:00 of the first day of the next month. Note that the appropriate path names and time information for the demonstration files were set when you loaded the GUI settings.

e) Click the "Start Subsequent Burial" pushbutton. When the "Wave Height and Period Grid" input GUI appears, change the values (from top to bottom) to the following numbers: 40, -71, 0.25, 0.25, 5, 5.

f) After the scour module is run, color images and AVI movies of predicted burial may be made from the "Analysis Tools" tab GUIs as described in Sections C3 (e-f) above.

Appendix D
INPUT DATA REQUIREMENTS

A. *Bathymetry*: (needed by all modules): The file must be three-column ASCII files, with each row giving latitude, longitude and depth in that order. The location of this file is specified in the "Ocean Data" tab. Land is flagged by the number -999.

B. *Sediment Type* (needed by scour module): Must be in either *.s output file format from the Sediments 2.0 data base or in three-column ASCII files, with each row giving latitude, longitude and median grain size (in millimeters) in that order. The grid for the sediment file must match the grid for the bathymetry file. The location of this file is specified in the "Ocean Data" tab. Land flags are "-999." No data flags are "-888."

C. *Sediment Layering* (needed by the impact module): This data may be manually entered in the "Sediment Layering" tab or imported from an ASCII file (under the "File" menu -> "Import IMPACT35 Sediment File" option). The ASCII file format is as follows: row 1 – one number specifying the number of layers (cannot exceed 20), subsequent rows – bearing strength (in pascals), density (in kg/m^3) and depth (in meters).

D. *Mine parameters* (needed by the impact module): The user manually enters inertial and kinematic properties of the mine under the "Mine Seeding/Impact" tab (in MKS units).

E. *Peak wave period, wave height, orbital velocity and current velocity data files*: (needed by the subsequent burial modules): One of two formats may be used:

   a). SWAN format: Flat ASCII files that are in SWAN output format 3[1]. The first number of the first row is the wave data at the southwest corner of the computational grid. The rest of the row is the wave data along the southern boundary of the computational grid, going from west to east (assume M data points along the west to east direction). The subsequent row corresponds to a grid point one row to the north, and so forth until the northernmost row is reached (assume N data points along the north to south direction). The next block of N by M data points corresponds to the data for the next time step. This pattern repeats until the last time step is reached in the file (assume T time steps). Both wave height and wave period files must be identical in size (N*T by M in size). Land flags are "-1."

   b). MAT-files: MATLAB formatted files. The data provided with this file format are one-dimensional time series data. After DMBP ingests the data, the program reproduces the data at each non-land grid node to make a two-dimensional gridded data set.

[1] N. Booji, J.G. Haagsma, L.H. Holthuijsen, A.T.M.M. Kieftenburg, R.C. Ris, A.J. van der Westhuysen, and M. Zijlema, 2004. SWAN Cycle III version 40.41 User Manual, Delft University of Technology, The Netherlands.